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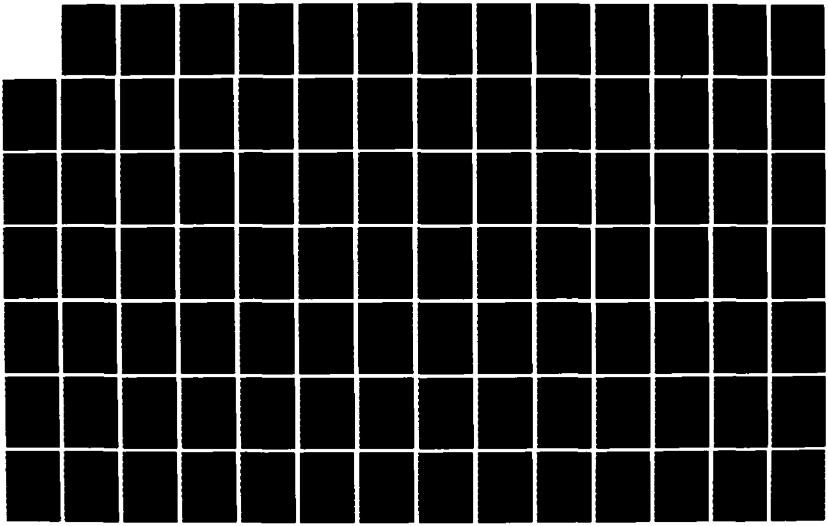

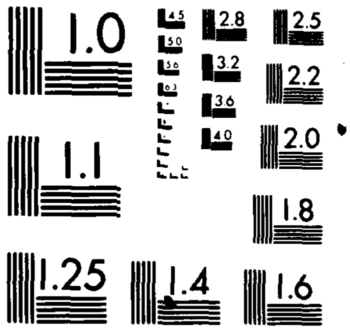

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AD-A172 526

HOW THE TIMING OF UPDATES ON
THE LOCATION OF STRATEGIC
RELOCATABLE TARGETS CHANGES
THE PROBABILITY OF DETECTION

THESIS

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HOW THE TIMING OF UPDATES ON THE LOCATION OF STRATEGIC RELOCATABLE TARGETS CHANGES THE PROBABILITY OF DETECTION

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
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Requirements for the Degree of
Master of Science in Operations Research

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Preface

The purpose of this study was to determine the relationship between the timing of intelligence updates on the location of strategic relocatable targets (SRT's) and the probability of detection. A simulation was designed to represent a bomber mission attacking an SRT. Only notional numbers were used in building the model, but the model should still produce valid results with real world data.

Most research involved classified information, and imposed some limitations. Many generalities were used to describe the problem to avoid using classified information. Also verification and validation checks were completed using notional numbers. However, the final model is still as valuable as the accuracy of the input allows.

Strategic relocatable targets are a growing concern of strategic planners. New technology makes war fighting more difficult and new procedures have to keep up with the trends that are present. This project is meant to remove some of the uncertainty dealing with strategic relocatable targets.

By applying this simulation to real world situations, the probability of mission success of the strategic bomber can be improved. Results of simulation runs will indicate the expected detection probability for each of a series of update times. A decision maker can then decide what level of mission success he wants as approximated by the detection probabilities and apply his resources accordingly.

In researching the SRT issue and completing the thesis, others have contributed their time and effort. I am deeply indebted to Maj Bill Rowell for his help in researching the topic and assistance and patience in editing the text. Also, many thanks to the B-1 project office at Wright-Patterson AFB, especially Mr. Jerry Sutton who suggested the topic and, who along with Maj Meagher, assisted throughout the project. I also wish to thank Capt Bill Hanson at Strategic Air Command Headquarters as well as Maj Ron Trees and Lt Col Jim Bexfield at the Pentagon (Bomber Division of Studies and Analyses) for their valuable inputs and forwarding of critical documents. Finally, a much deserved thanks to my wife Colleen and daughters Jennifer and Sandra for their patience and understanding throughout the 18 months. For being ignored and fatherless for this term, they deserve the attention the end of this project will bring.

Donald B. Olynick

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Abstract

This project's primary goal was to determine the relationship between the timing of the last intelligence update with the probability of detecting a strategic relocatable target (SRT). A computer simulation of a bomber attacking an SRT was built to develop the relationship. Many characteristics of a bomber aircraft and an SRT were investigated and included in the model to ensure a reasonable representation of the actual system. After integrating the significant factors into a comprehensive model, experimental runs were made.

Notional numbers were used throughout the project. After completing the verification and validation stages, experimental data was run through the model to demonstrate the format of the output and usefulness of the model. From the example, inferences were made about the true relationship of the update timing and detection probabilities.

Experimental results indicate that a significant decrease in detection probabilities occurred when the last update on the target's location is received by the attacking aircrew at a point where the time remaining until entering the search area is less than half the dwell time of the SRT. Therefore, this model not only provides the detection proba-

bility a decison maker can expect at each update time but also the point where significant changes in the probability of detection occurs.

HOW THE TIMING OF UPDATES ON THE LOCATION OF STRATEGIC RELOCATABLE TARGETS CHANGES THE PROBABILITY OF DETECTION

I. Introduction

Background

Fighting a war involving strategic relocatable targets (SRT's) complicates the role of the strategic bomber. Until recently, attacking strategic targets was straight forward. A bomber, knowing the target's exact location, would fly a planned flight path, identify the target, and release the appropriate weapon. However, times have changed. Today, a new class of targets has become increasingly important; a class of targets that can change location throughout the planning and execution phases of a war. These strategic relocatable targets pose a new threat to strategic bombing because of the uncertainty about their location. To combat this new threat, new procedures must be developed to improve a bomber's chance of finding and destroying an SRT. But before old procedures can be discarded and new procedures implemented, information regarding SRT's must be gathered.

Since the ultimate goal is to ensure bomber aircraft have the best chance of finding and destroying assigned targets, factors that significantly affect the bomber's chance must be examined. Attacking SRT's involves many fac-

tors which can be grouped into four primary areas: target, terrain, aircraft, and updates (13).

Target. Target movement is the main difference between strategic relocatable targets and static targets. Until the development of SRT's, bomber aircrews only had to rely on the aircraft navigation systems to guide them to the target area since the target location was known with certainty. Now, locating the SRT has become an added problem. While the SRT's location may be known at takeoff time, the target may move before the aircraft arrives. In trying to predict where the SRT will move, several questions come to mind. How fast does the target travel from one location to another? How far does the target travel before another stop is made? Once a new location is found, how long does the target stay in the same location before another move is made? Answers to these questions will help planners estimate a new SRT location for the aircraft arrival time. However, while characteristics of the target itself may provide some answers, information about the target environment will supply other answers.

Terrain. Terrain around the SRT can affect the speed of the target as well as limit the number of possible relocation sites. Terrain features such as dense forest or mountainous terrain can make relocation efforts very difficult. Average speed and distance traveled each move in this type of terrain can be considerably lower than for

terrain that allows good mobility. Even more, other terrain features such as lakes or mountain peaks may prove to be infeasible locations for deployment of an SRT. But in either case, information about the terrain can be very useful in forecasting the movement of the target.

Predictions about future locations of an SRT are easier if the possible movement area around the target's present location is reduced. Reductions in the area's size can be made due to slower SRT speeds and shorter moves by the SRT because of certain terrain features. In these cases, some segments of the movement area can be discarded from consideration. A smaller movement area means a smaller search area for the aircraft. Then, because of other aircraft constraints, a smaller search area can improve the probability of mission success.

<u>Aircraft</u>. During mission planning, tradeoffs among the aircraft factors have to be made to ensure mission success. Aircraft are limited by allowable search time and fuel constraints when searching for an SRT because of other mission requirements such as more targets to attack or recovery procedures. The amount of area covered during the allotted search time will depend mostly on the aircraft's speed and altitude.

A faster speed will allow the aircraft to cover more area and a higher altitude will provide a larger search radius (distance the aircraft can see). However, flying faster burns fuel at a higher rate and therefore could force

the aircrew to end the search early due to low fuel. Also, exposure to enemy defenses, aircraft equipment limitations, and the target detection factor (how well the target can be seen) are other aircraft factors that need to be considered. When making tradeoffs between the probability of locating the target versus the aircraft probability of survival, these three factors contribute to the probability of mission success. To a certain extent the aircraft routing, speed, etc., can be adjusted as the mission requirements change. But in order to increase the likelihood of mission success, accurate intelligence information on the SRT must also be provided.

Updates. Updated information on an SRT's location prior to the aircraft arrival could reduce the mission to one of an attack on a static target. If the final update is received "close" enough to the aircraft arrival time, the target will not have a chance to move and the aircraft can attack as it would against a static target. The "farther" (earlier) away from the aircraft arrival time that the final update is received, the more the target has an opportunity to move. This situation reduces the likelihood of target detection because more target movement translates into a larger area for the aircraft to search. As the search area increases, the probability of finding the target decreases due to the extra time required for the search and increased area for the target to hide. Similarly, as the time of the

last update becomes closer to the aircraft's arrival time into the target area, the probability of target detection decreases. But how "close" should the update be to produce a satisfactory detection probability?

The best time to pass updated information to the aircrew is when the aircraft enters the target area. However, more flexibility in allocating intelligence resources would be available if updated information can be given to the aircrew at an earlier time but not significantly reduce the probability (chance) of finding the target. In other words, instead of trying to get updated information to all aircraft at their search area arrival time, the information could be passed to the aircrews at any time during a specific time interval. If an aircrew receives their update within the specified time interval, decision makers would be confident that target detection probabilities would not be significantly reduced from that of a "closer" update. By computing and displaying the relationship between the timing of the update and probability of detection, the decision-maker would be able to accurately assess the likelihood of finding and destroying the SRT and allocate intelligence resources appropriately.

Problem Statement

To attack strategic relocatable targets, bomber crews must receive intelligence updates on the location of the target in a timely manner. However, not much is known about

how the time of the update affects the probability of target detection.

Objectives of the Study

Three primary objectives highlight the overall goal of this research project. The first objective is to model the movement of a strategic relocatable target. Characteristics of SRT's are investigated to identify important factors affecting the target movement. A second objective is to write a computer program to simulate an aircraft mission against an SRT. One computer run will simulate a series of aircraft missions and a detection probability will be computed for that set of missions. More computer runs will be done for a specified number of update times with a detection probability computed for each time. Finally, the third objective is to plot the detection probabilities against the corresponding update times. Confidence bands will also be computed to specify the range of accuracy of the estimate. Completion of these objectives will accurately describe the relationship between update times and detection probabilities.

Literature Search

Classified Documents. Much is still unknown about strategic relocatable targets and most information published is classified. Headquarters Strategic Air Command (SAC) is very interested in any aspect of SRT's for future mission planning and has written documents concerning SRT's. Clas-

sified documents outlining SAC's views on SRT's were reviewed for background information. While classified information will not be discussed in this paper, the documents supplied valuable information about which variables concerning strategic relocatable targets need to be considered in the simulation model. But just understanding the variables involved does not answer all the questions. Moving from areas of certainty (static targets) to areas of uncertainty (SRT's) also requires some background in probability theory.

<u>Probability Theory</u>. Basic concepts about probability distributions were reviewed to discover how an SRT's future location could be estimated. Discussions on stochastic processes provided insight about how probability distributions change from the present time to future times (4:376). This information helped devise an initial unconditional probability distribution of the target's location. Procedures were then investigated to develop the probability distribution of an SRT's movement and, together with the initial conditions, to estimate the probability of future target locations. From this set of possible locations a search pattern can be developed for the aircraft to ensure the "best" areas are given first priority in the search.

<u>Search and Detection Theory</u>. To estimate the probability of SRT detection for any update time, the model must include a method for the aircraft to search for the target. Research uncovered several sources to help decide on the

appropriate pattern to ensure a high probability of mission success.

Many journal articles have been written on search and detection theory. In his book, Search and Detection Theory, Alan R. Washburn summarizes the past findings and claims that up to now search theory is not really concerned with optimal search "paths" which are required for a realistic search pattern for an aircraft (16:1-1). He states two reasons as the primary causes. First, an optimal path is not useful unless it is easy to follow. Second, he asserts that a "path" is not a convenient mathematical object (16:1-1). Based on these reasons, most research, according to Washburn, involves a distribution of effort over an entire search area to maximize the probability of detecting the target (16:1-1).

A review of recent literature concerning search and detection theory confirmed Washburn's observation. S. S. Brown in one of his recent articles elaborated on an optimal search plan that allocated a search effort in each of a finite number of time intervals to maximize the overall probability of detecting a moving target (3:1275). A book by L. D. Stone stated the basic problem in search theory is that of maximizing the probability of detecting the target within a limited resource such as time or fuel (12:32). Finally, another article by Luke Tierney and Joseph Kadane defines a "search strategy" as "an allocation of the available search effort" (15:720). In these and other examples,

while a search path is not directly ignored, emphasis is placed on an allocation of search effort instead of the search pattern used to find the target.

A myopic search algorthim presented by Washburn can be used to develop a search pattern for an aircraft (16:6-4 - 6-8). Patterns resulting from a myopic search may prove infeasible for an aircraft to fly but by modifying the procedure slightly the probabilities derived will initially put an upper bound on the probability of finding the target.

Another source of information concerning SRT's was a segment of HQ Air Force Studies and Analyses Advanced Penetration Model (APM). The APM simulates an entire bomber mission (14:slide 3). In the model, movement of an SRT is disregarded after the war begins. But, because some aircaft missions may be quite long, SRT movement can almost be assured before the aircraft arrives. Also, another problem with the APM segment is that an exhaustive search (a pattern that searches the entire area) is used. (14:slide 10). An exhaustive search may prove infeasible because required search time is too long and aircraft fuel reserves could become too low to fulfill other mission requirements or to recover safely. Strategic planners today envision only one trip through the search area with at the most only one turn not to exceed 90 degrees (Fig. 1.1) (5,13).

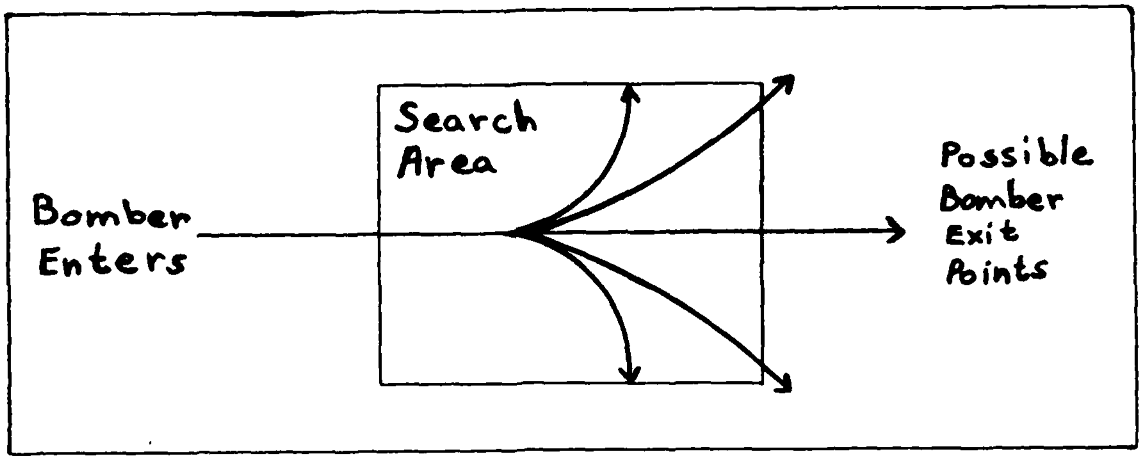


Fig. 1.1 Expected Flight Path of Aircraft Through a Search Area

Scope and Limitations

Target Type. Knowledge of the type of SRT being attacked is required in order to model the movement of the target and predict future locations. SRT's are either time constrained or time critical targets (11:2). Time constrained targets have a dwell time (time remaining in one spot) greater than the weapon system cycle time (11:2). Weapon system cycle time is the total time required from detection of a change in target location to weapon system arrival (10:7). Time critical targets have a dwell time less than the weapon system cycle time (11:2). Classifying an SRT in one of these two categories allows an appropriate weapon to be selected for the attack.

Weapon Type. One of the problems facing strategic planners is the type of weapon system to use against an SRT. In general, either missiles or bombers can be used against SRT's (10:7). Missiles can get to the target faster but

lack the flexibility of a bomber. Also, missiles need an accurate target location when they are launched. Therefore, missiles can be used more effectively against time constrained SRT's since no movement will take place before the missile arrives.

On the other hand, bombers are needed for time critical SRT's because movement of the target will occur even before a missile could arrive. Bombers provide the flexibility to apply a constrained search for the SRT and attack when the target is found (11:61). Since bombers are the primary concern of this project, the assumed scenario will be bombers attacking time critical targets or targets with very short dwell times. But before a bomber can attack an SRT, information concerning the target itself is needed.

SRT Characteristics. Research into the SRT question shows that some factor values about SRT's are known with certainty but little is known about other factors. First, even though SRT's move around, they do need a home base for certain support requirements (11:2). This will limit the full range of movement. Also, unless a war is in progress, there is no reason to relocate the target (11:2). Movements from the home base may occur due to training but these distances will be small. Therefore, it can be assumed that at the start of hostilities the target will be at its home base and will not stray more than a specified distance from that base throughout the war. Further, target characteristics such as speed, dwell time, target type (mobile or

movable), set up and tear down times, and possible location sites are all assumed to be known.

Methodology

Simulation Model. Because of the complexities and number of variables involved in computing detection probabilities of SRT's, simulation was chosen as the general approach to solve the problem. Simulation is a way to represent the behavior of a system as it changes from state to state according to a set of well-defined operating rules (9:6). For the purposes of this project, the state of the system will be the location of the target at each time period. Each type of SRT in every possible region represents a new situation requiring different values for the variables of the system (dwell time, setup time, etc.). For example, an army garrison moving in mountainous terrain would require different input values than a mobile missile unit in flat terrain. Many situations such as these can be modeled with a computer simulation by inputing different combinations of values for the factors.

The flexibility of simulation allows the desired results to be computed with an opportunity to test other aspects of the SRT mission. For instance, the army garrison mentioned earlier would have different input values for speed, detection factors, set up and tear down times, etc., than the mobile missile unit. However, both situations can

be modeled by just changing the input information with no changes required in the actual model.

Developing the simulation model involves two different theories. First, target movement is modeled as a stochastic process. A stochastic process is a collection of numbers each of which represents the value of a particular variable for each specified period of time (2:1). Second, optimal search theory and associated search patterns are investigated. One search pattern will be used for all aircraft missions to ensure results are not biased toward a particular search pattern.

Design of Experiments. A statistical design of experiments is the "process of planning an experiment so that appropriate data will be collected which may be analyzed by statistical methods resulting in valid and objective conclusions" (7:2). When the experiment is completed, significant factors (those that have significant effects on the results) will be identified. Knowledge of these factors will aid in the future analysis of the computer runs.

A scientific approach was used to determine which factors are critical to the final results of the simulation. To determine the relationship between update times and detection probabilities, all critical factors must be held constant as the update time is changed to ensure the change in the resulting detection probability is only due to the change in the update time and not other critical factors.

Then a good estimate for the detection probability at each update time can be calculated.

Estimating the Probability of Detection. An aircraft mission will be simulated as it attacks an SRT. Movement by the target will be started at time zero of the simulation and continue until one of the termination conditions is met. An update on the target's location will be simulated at some specified time before the aircraft begins the search. Applying the updated information, the aircraft will search for the target and record either a hit or a miss for each mission simulated. Many missions will be flown at each update time and the percentage of hits will be used as an estimate of the detection probability for that update time. Each probability with the corresponding update time can then be plotted to display the desired relationship.

Sequence of Presentation

Following Chapter 1, Chapter 2 explains the theory and procedures used to model the target movement. Chapter 3 continues by describing the aircraft mission, how the probability distribution for the target's location is computed, and how the aircraft searches for the target. In Chapter 4, the simulation model is explained as well as how the aircraft and target models are integrated. Chapter 5 discusses the validation and verification of the model. An experimental design used to identify key relationships among the factors is explained in Chapter 6 along with the analy-

sis of the simulation runs. Finally, Chapter 7 discusses the value of the model and some areas where further research may be useful.

II. Modeling Target Movement

Introduction

An aircrew must have some information about an SRT's pattern of movement to make accurate estimates about the target's future locations. Chapter 2 begins by relating an SRT's movement to a stochastic process and explains how the properties of a Markov chain are used to model the target's movement. Next is a discussion on the meaning and development of the one-step transition matrix. Finally, a description of the two types of SRTs is presented as well as how to compute the time unit of the stochasic process for each type of target.

Stochastic Processes

An aircrew of a strategic bomber preparing to attack an SRT is interested in the location of the target at the time the aircraft enters the search area. At some point in time prior to an attack on an SRT, intelligence information would report the exact location of the target as is currently done with static targets. However, since an SRT moves, the location at (future) times t_1, t_2, t_3,... is desired. At each time, t_i, a value is observed for the random variable shown as X_{t_1}, X_{t_2}, X_{t_3},...(1:293). A set of random variables $\{X_{t_i}: t_i \in T\}$ is called a stochastic process and T is called the index set $\{t_1, t_2, t_3, \ldots\}$ of the stochastic process (1:293). To obtain analytical results when evalua-

ting the process, assumptions about the joint distribution of X_{t1}, X_{t2}, X_{t3},... are necessary (4:372).

One possible assumption is that the stochastic process is a Markov chain. A Markov chain assumption eases the analytical computations in making inferences about a stochastic process (4:372). However, a finite-state Markov chain must satisfy four requirements (4:373):

1. A finite number of states
2. The Markovian property
3. Stationary transition probabilities
4. A set of initial probabilities $P\{X_0=i\}$ for all i

To explain how each requirement is applied to an SRT and to illustrate how SRT's can be modeled as finite-state Markov chain, the following discussion introduces a small example.

Finite Number of States. In describing an SRT's movement as a stochastic process, the state of the system at time t_i is the location of the target. To define the location, each SRT is assumed to stay within a specified range of its main operating base (MOB) due to support requirements (11:2). Therefore, a square box can be drawn around the MOB to define the area of movement. Within the large square, smaller square cells, which will be referred to as grids, can be drawn. Even though the size of the grids may vary, a finite or countable number of grids will always exist. The state of the system (target location) at time t_i can be defined as the number of the grid occupied by the target at time t_i.

As an example, suppose an SRT is restricted to a 15 mile radius of its MOB. Assume further that the grid size is 10 miles square. A square drawn around the possible movement area and divided into appropriate grids would reflect the situation depicted in Fig. 2.1. Nine grids (states) make up the possible location for the SRT. The grids are numbered from left to right and down the box as shown. Whereas maximum travel distance by the SRT and grid size may change, each situation involving an SRT can be modeled in this way. A finite number of states is therefore established for the process.

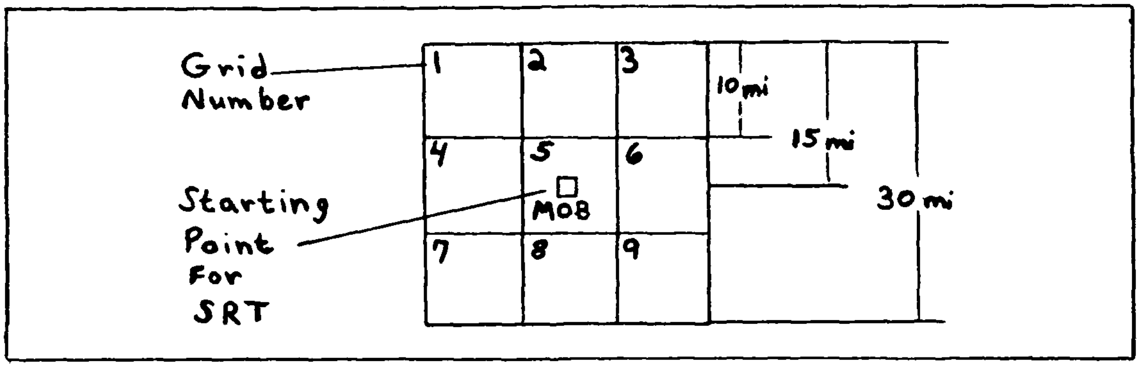


Fig.2.1. Typical Search Area

Markovian Property. Simply stated, any stochastic process with the Markovian property implies the future state of the system depends only on the current state and not on any state observed in the past (1:294). In a more rigorous fashion, the conditional probability of any future state given any past state is independent of the past state and depends only on the present state (4:372).

Assume the SRT in the previous example starts at its MOB in grid 5 and moves to grid 4, 1, and 2 in three consec-

utive time periods. The conditional probability of moving from grid 2 to any other grid is independent of how the SRT got to grid 2. Being in grid 2 at the present time is the driving factor. If the SRT had moved to grids 6, 3, and 2, the conditional probabilities for the next move would be the same as if the SRT moved through 4, 1, and 2. Not only does this fact show the existence of the Markovian property, but it introduces the idea of conditional probabilities.

Stationary Transition Probabilities. Conditional probabilities in a Markov chain are called transition probabilities (4:372). Mathematically, transition probabilities can be defined as $P\{X_{t+1}=j \mid X_t=i\}$ which represents the probability that the state of the process at time t+1 will be j given at time t the state of the process is i (4:372). To be considered stationary, an added restriction is introduced.

To be stationary, the probability of moving from state i in time period t to state j in time period t+1 must be equal to the probability of moving from state i in time period 0 to state j in time period 1. This relationship must hold for all possible grids i and j. In mathematical notation:

$$P\{X_{t+1}=j \mid X_t=i\} = P\{X_1=j \mid X_0=i\} \text{ for all } t=0,1,\ldots, \quad (1)$$

The individual probabilities are denoted by p_{ij} (4:372). Another look at the previous example will help define the transition probabilities.

Starting from grid 2, assume the target has a 0.3

probability of moving to grid 1, a 0.4 probability of moving to grid 4, and a 0.3 probability of moving to grid 5. The situation is depicted in Fig. 2.2. Assume further that three time periods have passed. Identifying one case, Fig. 2.2 shows the the $P\{X_4=1 | X_3=2\} = 0.3$ where t=3 is

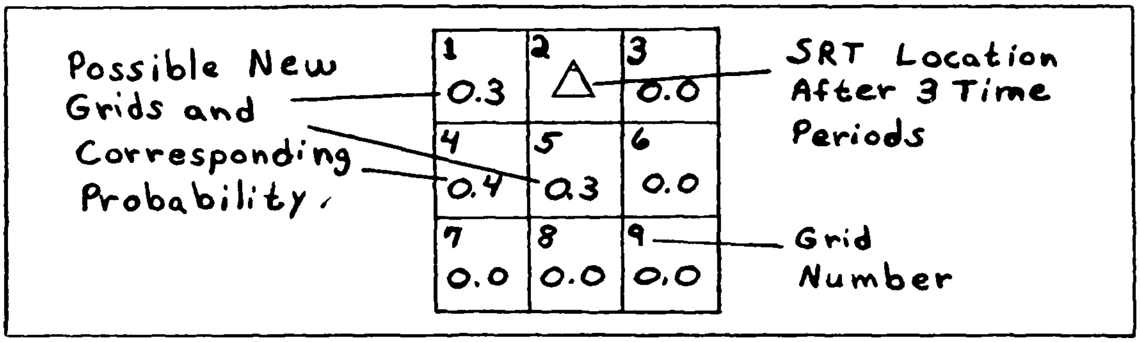


Fig. 2.2. Probable Movement of Target From One Grid

the current time period. An equivalent statement could be made about grid 4 or grid 5. To be considered stationary, $P\{X_4=1 | X_3=2\} = P\{X_1=1 | X_0=2\} = 0.3$. In other words, once in grid 2, the conditional probability of moving to any other grid must be the same whether the move takes place at time 0, at time 1, or at time n. There is no evidence in the available literature (10,11) to suggest that restrictions are placed on SRT's that would change the conditional probabilities from one time period to another; therefore, the probabilities are assumed to remain the same for all time periods and can be considered stationary. Conditional probabilities give insight into the probabilities of transitioning from one state to another, but if the unconditional probability of a future location of the SRT is desired, the

probability distribution of the initial state is also required (4:376).

Initial Conditions. In order to specify the initial probability distribution, the SRT's location must be known at some point in time. Considering the example again, if the SRT is observed in grid 2, the time of observation is t_0 and $X_0=2$. The initial probability distribution would show the $P\{X_0=2\} = 1$ and $P\{X_0=i\} = 0$ for all $i \neq 2$. Knowledge of this distribution satisfies the fourth requirement for a Markov chain and combined with the conditional (transition) probabilities, future unconditional probabilities can be calculated. A convenient method for computing the probabilities is through matrix operations.

What is a Transition Matrix

Transition probabilities can be represented by matrix notation as follows (4:373):

$$P^{(1)} = \begin{bmatrix} P_{00} & - - - - - - - - - - & P_{0M} \\ - & & - \\ - & & - \\ - & & - \\ - & & - \\ - & & - \\ - & & - \\ P_{M0} & - - - - - - - - - - & P_{MM} \end{bmatrix} \qquad (2)$$

where p_{ij} = probability of going from state i to state j in one step (one time period). Using a 3 X 3 grid, assume the one step transition matrix is as follows:

$$P^{(1)} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \left[\begin{array}{ccccccccc} 0 & 0 & 0 & .5 & .5 & 0 & 0 & 0 & 0 \\ .3 & 0 & 0 & .4 & .3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .5 & 0 & 0 & 0 & .5 & 0 & 0 & 0 & 0 \\ .3 & 0 & 0 & .4 & 0 & 0 & 0 & 0 & .3 \\ 0 & 0 & 0 & 0 & .5 & 0 & 0 & 0 & .5 \\ 0 & 0 & 0 & .5 & .5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0 & 0 \\ 0 & 0 & 0 & 0 & 1.0 & 0 & 0 & 0 & 0 \end{array}\right] \end{array} \qquad (3)$$

More than likely, unconditional probability distributions will be required for more than just one time period in the future. Therefore, an expansion of the one step transition matrix is needed.

An n-step transition probability matrix displays the conditional probabilities, $p^{(n)}_{ij}$, of moving from state i to state j in n time periods. From the Chapman-Kolmogorov equations, the n-step transition probabilities can be computed as follows:

$$p^{(n)}_{ij} = \sum_{k=0}^{M} p^{(v)}_{ik}\, p^{(n-v)}_{kj} \quad \text{for all } i,j,n \text{ and } 0 \leq v \leq n \qquad (4)$$

Thus, the n-step transition matrix can be obtained by computing the nth power of the one step transition matrix. Therefore, given the one step transition matrix, the conditional probabilities for any time, n, can be computed. But the desired result is still the unconditional probability distribution of the target's location for the future time period n.

Unconditional probabilities can be computed by multiplying the initial probability distribution of the SRT by the appropriate n-step transition matrix. Assume the known

starting point in the example is grid 2. Then the initial probability distribution is p_0 = [0 1 0 0 0 0 0 0 0]. Multiply the row vector, p_0, by the one step transition matrix, $P^{(1)}$, and the results are p_1 = [.3 0 0 .4 .3 0 0 0 0] which means starting in grid 2, after one time period there is a 0.3 probability of being in grid 1, 0.4 probability for grid 4, and 0.3 probability for grid 5. If p_0 were multiplied by the 2 step transition matrix, $P^{(2)}$, the unconditional distribution would represent probabilities after two time periods.

In any case, the interpretation is the same. Multiplying the initial probability distribution vector times the desired n-step transition matrix results in the unconditional probability distribution for the state of the process after time n. Because so much information is embodied in the one step transition matrix, accurately developing the conditional probabilities is critical.

Developing the Transition Matrix

Associating each SRT with its area of movement creates a unique situation. To accurately model the target movement, an accurate one step transition matrix must be developed. There will be a row and a column for each grid in the movement area. From each grid, estimates must be made about the probability of the SRT moving into any other available grid in the next time period. Estimating the probabilities involves several considerations.

Considering the new grid, three situations could exist. First, the grid could contain terrain features such that an SRT could not move through the grid. In this case, the conditional probability of moving there would be zero. A second situation could be one where the terrain is such that the SRT may not have any place to set up and dwell but could move through the area enroute to another grid. Finally, a third case is a grid that will allow movement through the area and allow the SRT to set up. Knowing the characteristics of the individual SRT and terrain around its operating area will allow each grid to be classified as one of the three types.

Another consideration in developing the conditional probabilities involves the speed of the target. Faster moving targets can reach grids farther away in one time period than slower moving targets. Therefore, this consideration is dependent on the time period chosen for the stochastic process. However, grids farther from the current location will also have a smaller probability of being entered than closer grids.

Finally, the probability of staying in the same grid for two consecutive time periods will be assumed to be zero. From the known characteristics of the SRT, the length of time spent in one grid can be calculated. These are average times. If there is any chance of an SRT staying in one grid for more than one time period, it will be reflected in the average "dwell" time of the SRT. In this way a time unit

for the stochastic process (time between changes of state) can be developed from the average dwell time and a change of state must occur after each time unit. Development of the transition matrix is a key to modeling SRT movement but the type of target being modeled must also be known to develop the time unit of the stochastic process.

<u>Matching Target Type and Time Unit</u>

Strategic relocatable targets can be classified as either mobile or movable targets (11:2). A mobile target is a target that is always in motion and assumed to be at a constant speed. Thus the amount of time spent in one grid can be calculated as the grid size divided by the target's speed and the result used as the time unit of the stochastic process. Also, since the mobile target does not have to set up, there are only two kinds of grids rather than three (grids the SRT can enter and grids they can not). A mobile target will move randomly to an available adjacent grid after each time unit and the state of the system will change accordingly. Movable targets require a little more information to compute the time unit of the process.

Movable SRT's are targets that set up in one location for a specified time period then relocate to another position (11:2). Two pieces of information about the SRT must be known to accurately compute a time unit for the stochastic process. First, the total time spent in one spot must be given. A combination of set up time, dwell time, and

tear down time (time required to dismantle equipment to prepare for another move) make up the total dwell time spent in one spot. Once the SRT is ready to move, another time variable is introduced.

To move from one grid to another, the time required depends not only on the distance to move but also the speed of the SRT. Distances between possible set up points will vary. Therefore, an average distance per move must be calculated for each area. For a mobile target, the distance is always one grid, but for a movable target the distance can be longer (not shorter since it is assumed the grid number must change after each time unit). Dividing the average distance moved by the speed of the target will result in the average time required to move from one location to another. The actual distances moved will depend on the grid size selected. How the grid size is determined will be discussed in the aircraft model. For now, adding the average move time to the total dwell time becomes the time unit for the stochastic process for a movable target.

Conclusion

A model for moving the target can now be built for the simulation using Markov chain procedures. Development of the one step transition matrix and the time unit of the stochastic process are two key elements in modeling the SRT movement. Characteristics of SRT's are available in classified documents and to get realistic results, this classified

information must be accessed and used to develop the key input data. However, verification and validation of the model can be done with notional numbers. But to complete the model, an aircraft mission must be included to simulate the attack on an SRT so that the detection probabilities can be computed.

III. Modeling the Aircraft Mission

Introduction

To estimate the probability of detection, an aircraft mission attacking an SRT must be simulated. At many times planners will have no control over the target variables. But in the aircraft model most variables can be set as the planners desire. Therefore, a little more flexibility is needed to model the aircraft mission. Planners can adjust aircraft parameters such as speed and altitude to improve the probability of mission success. Since each SRT mission is unique, simulating the aircraft attack must be flexible enough to accept many values for the aircraft factors and integrate them to arrive at an estimate for the probability of detection.

Chapter 3 describes the model of the aircraft mission. First is a discussion about what makes up the system cycle time and how the aircraft mission is modeled until the search begins. An explanation of the search pattern used by the aircraft to look for the SRT follows including some comparisons among three possible search patterns. Third, intelligence updates are introduced with a discussion on how the aircraft makes adjustments. Finally, the fourth section explains the conditions for terminating a single aircraft mission.

System Cycle Time

System cycle time is the total time required from detection of a change in a relocatable target's location or status until the weapon system arrives at the target (10:7). Because the target location is not known with certainty, the weapon system arrival time assumed in this model will be the arrival time of the aircraft at the edge of the search area. System cycle time can be broken into five segments but with some overlap involved in certain situations.

Intelligence Cycle Time. Intelligence cycle time is the first part of the total time. Time starts when a change in an SRT's location is detected and ends when the information is in the hands of the mission planners (13). Usually military staff planners or the crew members flying the mission do the flight and target planning. However, the main point is that there is always a delay from when a change occurs in an SRT location and when plans can be made to attack the target at the new location. This delay is input into the aircraft model as a constant to allow realistic target movement to occur while the aircraft is preparing for the attack.

Mission Planning. The second part of the system cycle time is mission planning time. Once new information reaches planners another delay is encountered while the actual aircraft mission is planned (13). Crew members or higher level planners can accomplish this task. Mission planning time may not be applicable in some cases such as when staff

officers plan the attack. In these cases, mission planning time runs concurrently with crew rest.

Crew Rest. Crew members must be afforded certain rest time before flying the required mission which constitutes the third part of system cycle time. As stated earlier, if crew members do not plan the mission, crew rest can run concurrently with mission planning time and only one delay needs to be considered. However, even if the time runs concurrently, a small delay is still needed to account for briefing the crew on the mission before they takeoff.

Preflight Time. As the fourth part of system cycle time, any ground delays such as preflight and taxi time must be considered in the model. Other delays may also be encountered due to alert time or unexpected maintenance problems prior to takeoff (13). An average expected delay can be computed for these circumstances and should always be included in the model.

Flight Time. The final delay in the system cycle time is the actual flight time to the search area. Each aircraft mission must account for the time from takeoff until the aircraft is in a position to begin the search. Target movement must be allowed to continue according to its schedule until the aircraft arrival at the search area.

After all five delays are computed, the total system cycle time is calculated as the sum of the five delays. In order to accurately estimate the aircrew's probability of

detecting the target, the target movement and the aircraft mission must be realistically integrated. All delays between the time the target location is known and the aircraft arrival time must be included to allow the target to move for the correct amount of time. If more or less time is allowed before the aircraft begins the search, the detection probability may be affected which will then bias the results away from the true probability of detection. For instance, if not enough movement is allowed, the location distribution for the target will cover a smaller area than it should which will incorrectly reflect a higher probability of detection. However, if the proper delays are accounted for, the unconditional probability distribution of the target's location will be a better representation of the real world and the search can begin with information as good as can be expected.

Aircraft Search

One search pattern must be selected and used for all computer runs so that any changes in detection probabilities can only be attributed to changes in the time of the last update. To accurately plot the relationship between detection probabilities and the time of the last intelligence update, all the aircraft factors except the update time must remain constant for all computer runs. In so doing, a change in detection probabilities from one update time to another will only be due to the change in the update time. Most of

the aircraft factors have values that can be derived from technical manuals or operational procedures. However, the search pattern is not so easily defined. Three search patterns were considered as possible ways to look for SRT's.

Exhaustive Search. When using an exhaustive search pattern, the entire search area is scanned. As depicted in Fig. 3.1, an aircraft enters from the upper left corner of the region and searches from left to right (14:slide 8). When at the right edge of the area a 180 degree turn is made

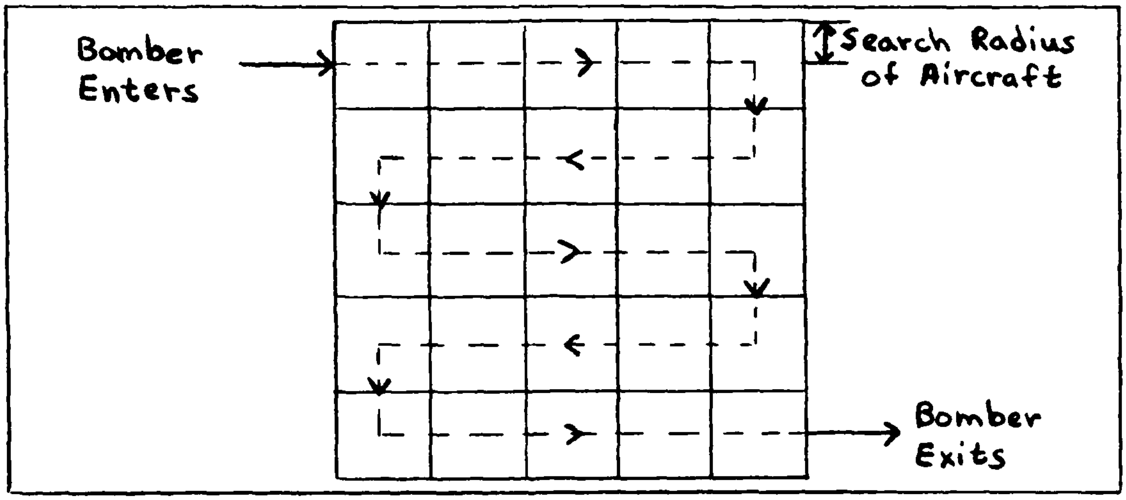


Fig. 3.1. Exhaustive Search

to reverse the direction and to search the next row of grids in the opposite direction. At the left edge the procedure is repeated. When the last row (bottom row) has been searched the aircraft exits the search area. By defining the size of each square grid as two times the search radius of the aircraft sensors, the entire area is searched which gives a high probability of target detection; however, there are some drawbacks.

To use the exhaustive search requires a lot of time and

does not use the updated information. Each aircraft will fly for a considerable time to get to the search area due to the location of probable targets. Also, each aircraft will usually be assigned more than one target per mission. With such long missions, fuel constraints and other mission requirements will limit the time available to search for each target. In addition, the entire area is searched regardless of any updated information that may be received. Therefore, an exhaustive search is impractical and a shorter search is needed.

Effort Distribution. One search pattern which requires less time is one which divides the total search time available among the individual grids to maximize the probability of detection (16:5-1). Initially the total available search time is given and defined as the total search effort. An assumption is made that spending more time (effort) searching a particular grid will increase the probability of detecting the target if the target is in the grid being searched. With this assumption, the unconditional probabilities of the target being in each grid are sorted from highest to lowest. The available search effort is then divided among the grids on the sorted list to maximize the probability of detecting the target (16:5-1). However, a problem with this search pattern is also encountered.

An effort distribution algorithm such as just described does not account for any movement of the target during the actual search. One of the assumptions made for the SRT

missions is that the scenario would involve bombers attacking SRT's with very short dwell times. Even though aircraft search times may be short, targets could move sometime after the search begins and before the search time is over. Therefore, a search pattern that allows target movement during the aircraft search must be used.

Markov Motion-Myopic Search. A myopic search pattern can adjust to target movement during the search (16:6-1). A myopic search is one which applies all available search effort for one time in the location with the highest probability of containing the target. In so doing, this search pattern maximizes the probability of detection for a specific point in time given the target has not been found in the previous time periods (16:6-5).

Three inputs are required to compute the unconditional probability distribution of the target's location using the myopic search pattern. First, the probability of the target being in each grid, x, at a time t without being detected by any previous search is needed (usually this will represent the initial position where t=0). Second, the probability that a target in grid x at time t will not be detected at time t must be known. Finally, the third input is the probability that a target in a grid x at time t goes next to grid y (this represents the transition matrix). Multiplying these three inputs together results in the unconditional probabilities of the target being in each possible grid at

time t+1 and not detected in the previous time periods. From these probabilities, the grid with the highest probability of containing the target at time t+1 is searched.

A myopic search pattern searches only one grid each time period to maximize the detection probability. However, for the SRT mission, several grids will be searched during one time period. Depending on how fast the aircraft flies, how large the grids are, and how much search time is allotted, any number of grids can be searched each time period. The goal is to maximize the probability of detecting the target given that a specified number of "looks" (grids searched) are allowed. Therefore, the pattern is modified slightly.

Only two of the previous inputs are required for the aircraft SRT mission. By using the properties of a Markov chain, multiplying the initial position vector (computed at the update time) times the n-step transition matrix results in the unconditional probability distribution of the target's location at the beginning of the search. The grids are searched from highest to lowest according to the probability of containing the target. Termination occurs when the target is found or when the allotted number of grids have been searched. If a time period ends while the search is in progress, new probabilities are computed and the search continues with the new results.

Using the modified Markov motion-myopic search pattern allows the aircraft to search the "best" grids first and

allows adjustments to target movement while the search in is progress. However, making the adjustments and getting the first set of unconditional probabilities requires computing the initial position vector and the n-step transition matrix.

Updated Information

Information at several update times will be simulated but no matter what the update time, the required calculations are the same. Target movement and the aircraft mission progress independently from one another. However, when an update time arrives, the initial position vector of the target as seen by the aircrew is reset to reflect the actual target location. The remaining time until the aircraft reaches the search area is then computed.

Using the time unit of the stochastic process, an estimate of the number of moves to be made by the target is calculated. From this information, the appropriate n-step transition matrix can be computed and subsequently the unconditional probability distribution of the target's location computed for the aircraft's arrival time. Also, an estimate is computed for the time of the target's first move after the aircraft begins the search. If a move is anticipated by the aircrew while the search is in progress, adjustments are made to the unconditional probability distribution of the target's location.

By ranking the unconditional probabilities of target detection from high to low probability, the aircraft can search grids with the highest probability of target presence first. Each aircraft mission will only be allowed to search a limited number of grids. If the aircraft searches the grid containing the target, a random number is drawn to test for target detection by the aircraft sensors based on the computed conditional target detection factor. If the aircraft estimates that the target is moving to another grid while the search is in progress, the (n+1)-step transition matrix is computed followed by calculation of the new unconditional location distribution. After the new distribution is sorted, the search continues in the grid at the top of the sorted list.

For example, assume the aircraft is initially given the following vector of grids to search: [4,3,6,5,1,2,7,9,8]. In addition, assume grid 4 has been searched and the aircraft is starting to search grid 3. If a move is anticipated, new calculations are completed. Assume further the new vector of grids (sorted from highest to lowest) is [9,8,6,7,5,4,3,1,2]. After searching grid 3 the aircraft will search grid 9 from the top of the new list rather than grid 6 from the old list. In this way, the most current information on the target's location is being used for the search. To arrive at the estimate of the detection probability, many missions are generated to get accurate results.

But before another mission can start, the previous one must be stopped.

Mission Termination Procedures

Search Time. Each bomber mission will be limited to a specific amount of search time. As mentioned earlier, currently SAC planners use one sweep through a search area as the time limit (5,13). Considerations such as other targets to strike and exposure to enemy defenses come into play when determining the actual limit. For the aircraft model, if the time limit runs out before the aircraft finds the target, the mission records a miss and checks are then done to see if the simulation run is complete or if another mission should be generated.

Minimum Fuel. Very closely related to the search time limit is the fuel constraint. In order to continue the mission and land safely, an aircraft will be required to end a search with no less than a specific amount of fuel reserve. If more search time is available when the check is done but the fuel reserves are below the minimum allowed, the aircraft will have to exit the search area. Again, if the target has not been found a miss is recorded for that particular aircraft mission and appropriate checks are completed as before.

Target Detection. Finding the target is the quickest way to terminate the aircraft mission. Two requirements must be satisfied before a hit can be recorded. First, the

aircraft must choose to search a grid that contains the target. If the correct grid is selected, the second requirement to be satisfied is that the aircraft sensors must be able to recognize the target. To model the sensors, a conditional detection factor is input as a probability. Then a random number is drawn to determine if the target is found (a random number less than or equal to the detection factor means a hit). Appropriate steps are then taken to end the run or generate another mission depending on the final checks.

Conclusion

Integrating the aircraft model with the target model will allow an estimate of the detection probability to be computed over a range of intelligence update times. Since the target continues to move throughout the simulation independent of the aircraft model, the timing of the aircraft mission is very important to ensure the target is given ample time to move around. As was indicated earlier, not allowing enough movement time could bias the detection probabilities to the high side. Also, by using a modified myopic search pattern for all aircraft missions and keeping all other variables constant, any changes in the estimates for the different update times can be attributed to the changing update time only. To integrate the two models, a computer simulation model is presented in the next chapter which is used to generate the data to compute the estimate

for the detection probabilities. From these probabilities, the desired plot of detection probabilities versus intelligence update times can then be drawn.

IV. Simulation Model

Introduction

Development of the simulation model requires an accurate description of the real world. Previous chapters have explained the factors affecting both SRT movement and aircraft SRT missions. Emphasis now turns to developing a model that will output an estimate for the probability of detecting an SRT for specified intelligence update times. Fig. 4.1 shows the flow of the entire simulation model.

After the computer languages used are introduced, Chapter 4 continues in a chronological fashion to describe the other activities in the simulation. First, initial conditions for the simulation are discussed. Next, procedures for moving the SRT are explained. Third is a description of how the aircraft mission is initiated, how receipt of intelligence updates are handled, and how the flight to the search area is modeled. Finally, the last two sections describe how the aircraft search is modeled and how the aircraft mission is terminated.

Computer Languages

SLAM. A Simulation Language for Alternative Modeling, called SLAM, is the primary computer language used for this model. SLAM is a FORTRAN based language that allows simulation models to be built using one of three different orientations (9:ix). In describing SRT movement and aircraft SRT

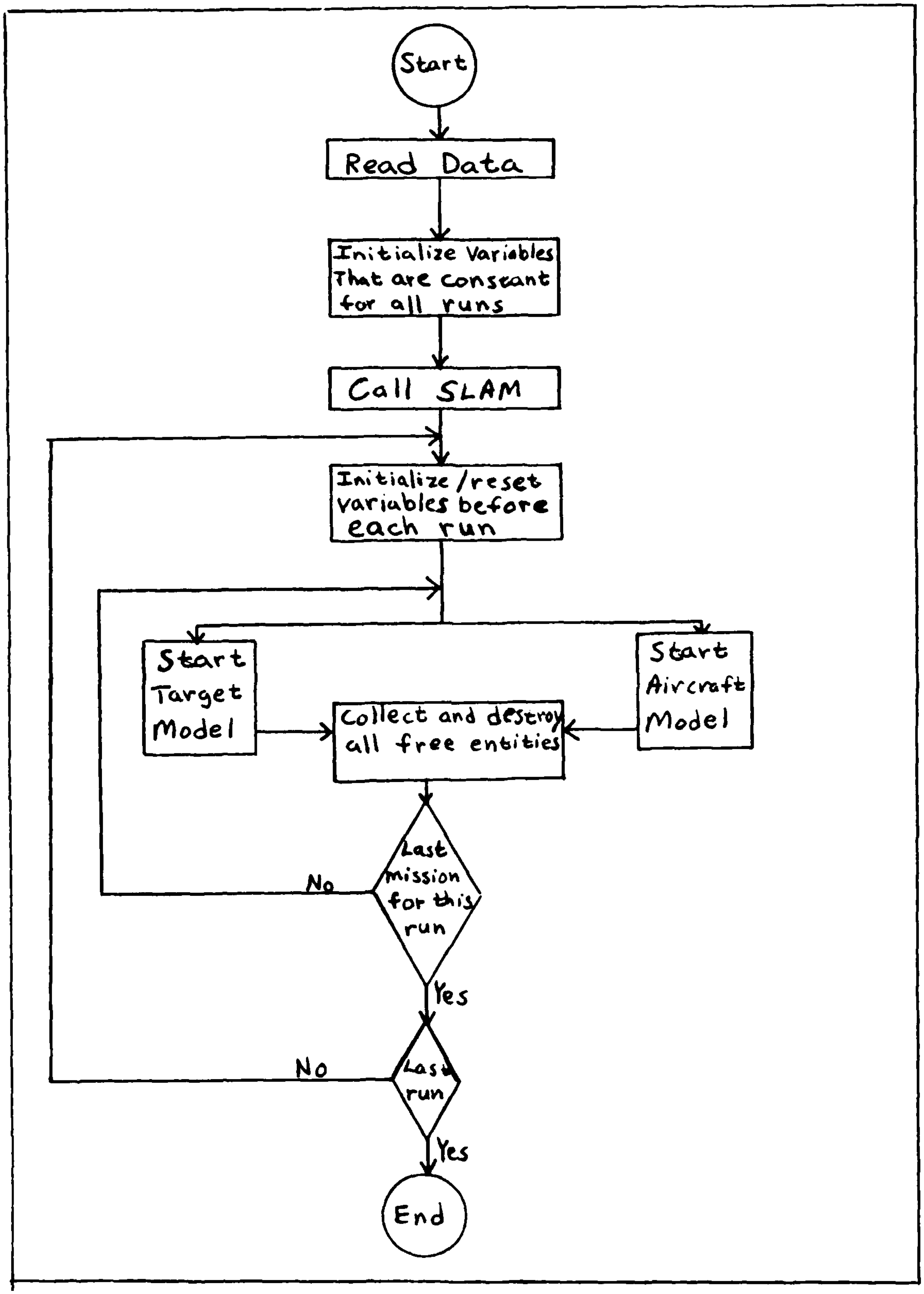


Fig. 4.1. Flow Chart of the Complete Simulation

missions, the orientation assumed is a combined network-discrete event orientation.

A network orientation or process orientation models the flow of entities through a defined process (9:78). Each aircraft and each target represent one entity or item in the SRT process. The process is the sequence of events and activities involved in moving the target and flying the aircraft mission. For the SRT model, the network will generate the flow of the aircraft and target entities from the beginning of the simulation until one of the termination conditions is met. While network orientations have the advantage of easier development, not all systems can be accurately represented by the available network elements (9:323).

In a discrete event orientation, the model is built by defining the changes that occur at discrete points in time called event times (9:229). At each event time the logic associated with the occurrence of that event is executed in a time ordered sequence (9:66). A model is built by identifying those events where changes in the system state occur and developing the logic to make the required changes in the system when the event does occur. Changing the state of an SRT mission involves updating the location of the target and can be done with the available network elements. However, other changes require matrix operations using with the Markov chain procedures and cannot be done within the network orientation. Therefore, to completely model the SRT move-

ment and the aircraft missions, a combined network-discrete event orientation is modeled.

By using the combined framework, the advantages of both orientations are enjoyed. Portions of the system that can be described by a network are modeled as a network with a discrete event viewpoint used only for portions that require the added flexibility (9:323). A reduction in modeling effort is realized since the major flow of the system uses the network orientation. Only the basic matrix algebra requires modeling outside the network. To accomplish the matrix operations requires interfacing the SLAM program with some FORTRAN subroutines.

FORTRAN. Each discrete event in the model is coded as a FORTRAN subroutine (9:236). As entities flow through the network, the time will come for the occurrence of a discrete event. SLAM allows specific coding to call the appropriate FORTRAN subroutine to perform the required functions (9:236). However, the entire simulation is controlled by the SLAM network including the simulated clock time.

SLAM advances time as appropriate and relieves the programmer of sequencing events in their proper chronological order (9:237). This allows the programmer to write independent units of code that can occur simultaneously while the simulation is running. A SLAM executive program chooses the "next event" to execute as the simulation progresses. When there are no events remaining on the next

event "calendar", the simulation is terminated and a new run can be initiated. However, at the start of every run, certain actions must be taken to initialize the model.

Time Zero Activities

An SRT is created at time zero and the movement started (Fig. 4.2 shows the flow of the target model). The center grid of the search box is identified based on the input data and the target is placed in the center position. An initial target location vector is developed to indicate the target's postion. Also, since no dwell time is assumed for the first move, a random direction is chosen and a delay time initiated for the time required to move the target to the boundary between the old grid and the new grid. As the target's position is initialized, the aircraft prepares for the mission.

A decision must be made about the first event to occur in the aircraft model before any activities can occur for this segment. The first event will either be the aircraft takeoff or the intelligence update (the flow of the aircraft model is shown in Fig. 4.3). If the takeoff occurs first, a delay must be initiated to account for the time until the scheduled takeoff followed by a delay for the flight time to the update point with a final delay for the flight time to the search area. Otherwise, a delay is initiated for the time until the update is received while still on the ground followed by other delays for the remaining ground time

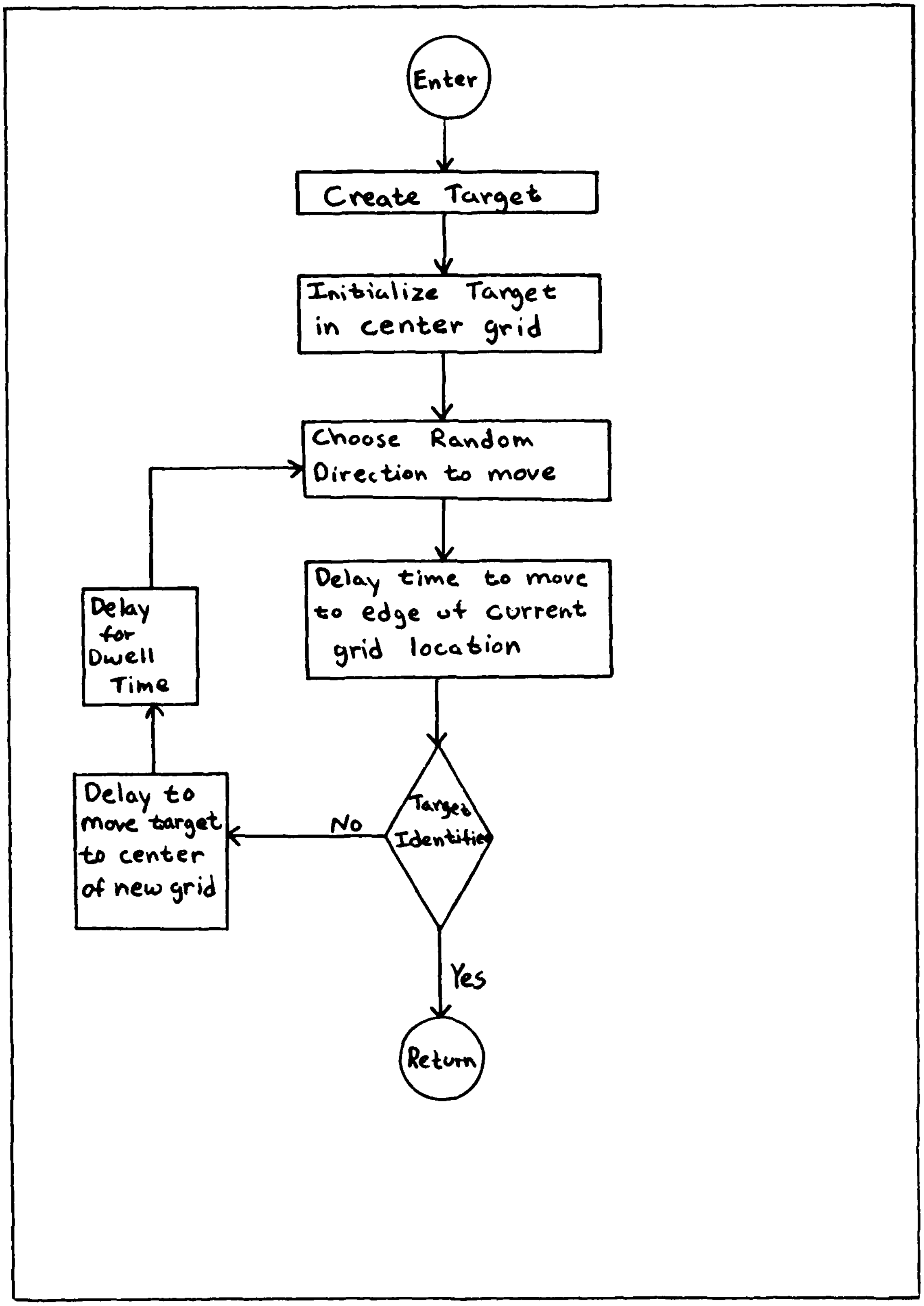


Fig. 4.2. Flow Chart of the Target Model

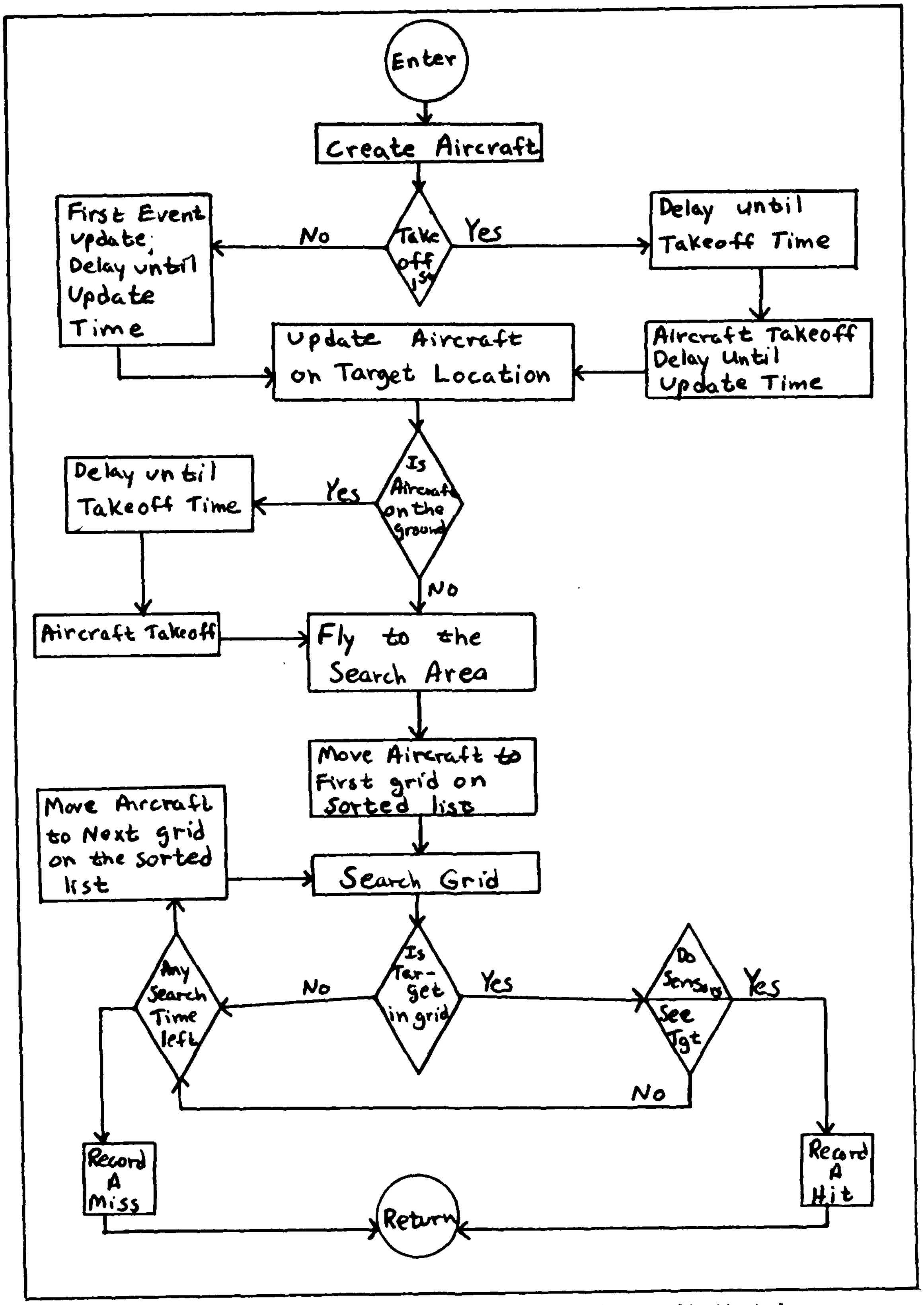


Fig. 4.3. Flow Chart of the Aircraft Model

and the flight time from the takeoff point to the search area. As the aircraft model continues, the target moves independently of any aircraft actions.

Continuous Target Movement

Before any move can be made, the relative position of the SRT inside the defined search "box" must be identified. A random direction is selected for the next move to be made by the SRT. However, depending on the position of the target relative to the search box, either eight, five, or three directions will be available to choose from. In the center area of the box, eight grids surround the current location and therefore one of eight directions can be selected (Fig. 4.4a). But if the target is on the boundary of the box, only one of five directions can be selected

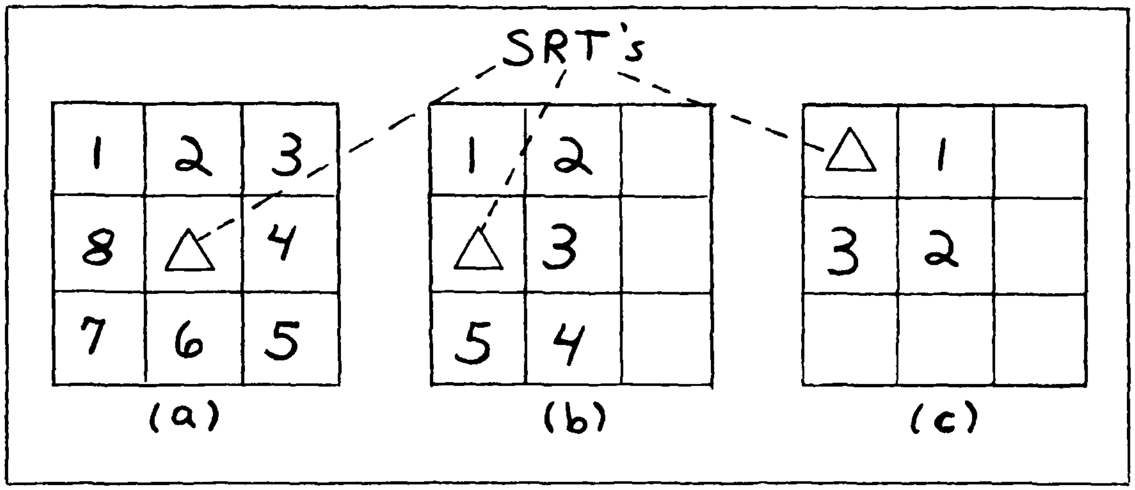


Fig. 4.4. Three Relative Positions Possible for the Target in the Search Area

because movement outside the box is prohibited (Fig. 4.4b). Even more restrictive, if a corner position is occupied, only one of three directions can be selected (Fig. 4.4c).

Determining the relative position of the target must come before a direction can be chosen. To determine the position, further screening must be accomplished.

For SRT's located on the boundary of the box, further tests must be done to determine exactly which edge or which corner is occupied. Imagine the search box in a north-south orientation as depicted in Fig 4.5a. From the center grid, eight possible directions can be selected, each representing

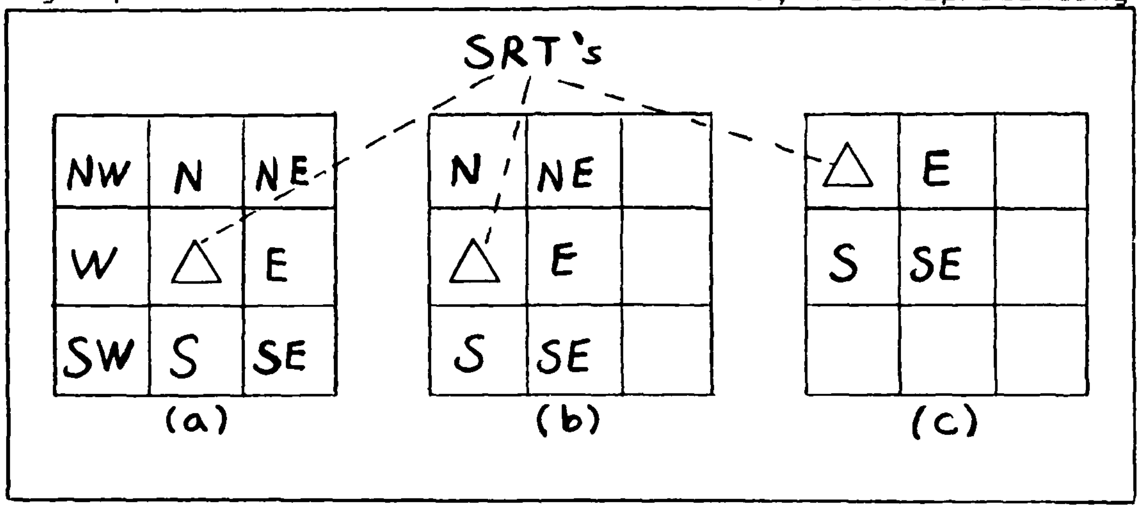


Fig. 4.5. Possible Directions for the Target to Move

a compass direction as labeled in the figure. Now consider the situation in Fig. 4.5b. On the "edge" of the box only five directions are available. Moving to Fig 4.5c, in a corner position only three directions are available (Note: To be consistent, the box is always oriented in a N-S direction and the eight compass points remain the same). Each of the four corners and each of the four edges have the same number of possible move directions but have a unique set of actual move directions (Fig. 4.6). Therefore, to determine which directions are possible from the current position, the

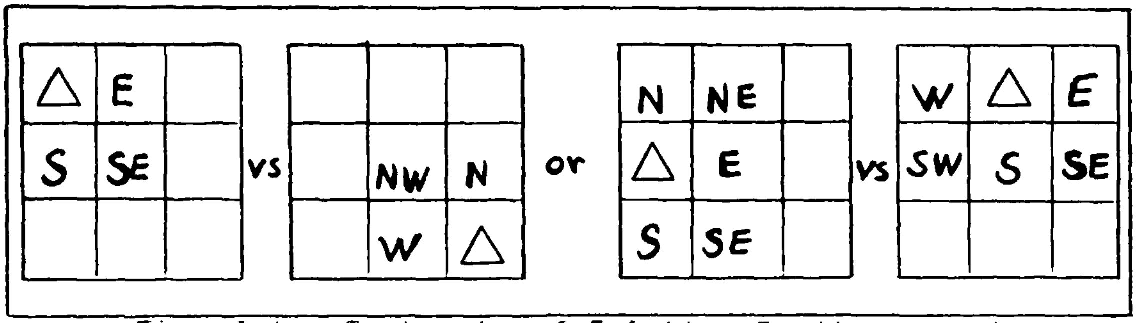


Fig. 4.6. Contrast of Relative Positions and Choice of Directions

exact location for boundary and corner grids must be identified.

Once the exact location of the occupied grid has been identified a new direction can be chosen. Branching within the simulation model will place the target entity in the appropriate section of code associated with its current position. A random number from a uniform distribution will be chosen. The range of the distribution will be zero to three, five, or eight depending on the situation. Each of the appropriate compass directions is associated with a subrange of the distribution and a direction will be chosen based on the value of the random number.

For example, if five directions are available, the direction parameters will be 0 to 5. A random number less than one will refer to one direction, between one and two another direction and so on until all five directions are covered. Once the new direction is chosen, the actual grid to be entered is computed. But before the move can be made, the status of the new grid must be checked.

A test must be done on the future location to see if it

is suitable for the move. With the input data, each grid is assigned a status of 0, 1, or 2: 0 means no passage, 1 means the target can pass through but not stop, and 2 means the target can pass through and stop. If the new direction will put the SRT in a grid with a 0 status, a new direction is chosen before any move takes place (no simulated time elapses). If a status of 1 is discovered, the move is made with the appropriate amount of time passing but another move is initiated before any dwell time is applied (for a mobile target, only 0's and 1's apply since mobile SRT's have 0 dwell time). Finally, if a grid with a status of 2 is selected the move can be made with a delay initiated representing the appropriate move time and dwell time. At the completion of the delay, the process repeats and continues until the termination of the mission.

Aircraft Update Procedures

While the SRT movement is being simulated, an aircraft mission continues according to the scheduled timing. As mentioned earlier, the aircraft will follow a certain sequence depending on whether the takeoff or update occurs first. In either case, time delays are built into the model to allow for an appropriate amount of random target movement up to the update time. But the update procedures are the same no matter what time the update occurs.

Simulating update procedures requires revealing to the aircrew the current location of the target. When the

update event occurs, the initial target location vector is changed to reflect the new position. Then, to compute the unconditional probability distribution of the target's location for the aircraft arrival time, the appropriate n-step transition matrix must be calculated. Since the one-step transition matrix is raised to th n^{th} power, to compute the n-step transition matrix the value of n must be known.

To find the value of n, the anticipated number of moves the target will make before the aircraft arrives is calculated. At the time of the update, intelligence sources do not know how long the SRT has been in the current location. To cut down on some of the error, an assumption is made that the target has been in the reported location for one half of the total time that is normally spent in one location. The aircrew will then anticipate a move after one half of the normal time has elapsed. After the first move, all future moves will be anticipated after a full time unit. Dividing the time remaining until the aircraft arrives (minus the time for the first move) by the full time unit will give (n-1) which is needed to compute the appropriate n-step transition matrix (for example, if two moves can be made following the first move which occurs after half a time unit, the value of n=3). When the value of n is known, the remaining calculations can be accomplished.

An unconditional location distribution must be computed to guide the aircraft in the search for the SRT. Multiplying the updated initial position vector by the n-step

transition matrix will result in the unconditional location distribution of the target for the aircraft arrival time. The grids are then sorted from high to low probabilities. Sorting makes programming the aircraft search easier because when the grids are selected from top to bottom on the ordered list the highest probability grids are searched first. When all update calculations are complete, the aircraft mission continues on its scheduled time until the aircraft arrives in the search area.

Aircraft Search

A search begins by moving the aircraft to the first grid on the sorted list. Since the maximum probability of finding the target is desired, searching the grids with the highest probability of containing the SRT first will achieve the desired goal over the long term. A check is done to see if the aircraft location (grid number) is the same as the target's actual location. If the locations are not the same, the process repeats for the next grid on the sorted list. However, if the locations are the same, a check is done to see if the aircraft sensors identify the target.

Sensor systems are checked by comparing a random number to the probability of detection associated with the sensors. Since the sensors are not perfect, inputs into the model can specify a probability distribution to account for errors in the system. A random number is drawn and compared to the conditional detection probability to determine the success

of the sensors for that particular "look" at the target. If a success occurs, a hit is recorded for that aircraft mission. Failure of the sensors is indicated by a message telling the decision maker that the aircraft found the correct grid but still missed the target due to the sensors. In this case, the search continues.

To continue the search, the next grid on the sorted list is selected by the aircraft. Before a move is made into the next grid a check is made to see if the probability of the target's presence is greater than 0. If not, the grid is not searched because time would be wasted in the long term. Instead the aircraft returns to the first grid on the sorted list and searches from the top of the list down again. But, if the next grid on the sorted list has a probability greater than 0 then the search is conducted as before. As the search continues, if the time anticipated by the aircrew for the next target move occurs, updated information must be calculated.

New unconditional probabilities must be computed if the target moves during the aircraft search. When the update on the target's location is received by the aircrew while enroute to the search area, a guess is made as to how long the target has been in the current location. At the same time an estimate is made about the time of the target's first move after arrival of the aircraft. The target may or may not move at that time but the aircraft anticipates a

move based strictly on timing. If the time of the anticipated move occurs during the search, the (n+1)-step transition matrix must be calculated and multiplied by the initial position vector calculated when the intelligence update was received. Sorting the resulting vector will give a new unconditional location distribution with which to continue the search for the SRT. Starting at the top of the list, the aircraft continues as before until one of the termination conditions is met.

Termination Procedures

Three conditions will terminate one mission of the simulation. First, if the aircraft finds the SRT a hit is recorded and the mission is terminated. Second, after each grid is searched, the allotted search time is checked to see if it has been exceeded. If too much search time has been used, a miss is recorded and the mission is terminated; otherwise the mission is continued. Finally, the third condition checks the fuel status of the aircraft. If the fuel level is below a specified minimum value, the aircraft must terminate the search and a miss is recorded. But, the mission continues if the fuel is above the minimum acceptable.

In all cases, when the mission is terminated, the procedures are the same. A specified number of missions are run for each update time being tested. When one mission is terminated a check is made to see if it is the last mission

for the current simulation run. If not, the aircraft and target entities are initialized to their starting positions and another mission started. After the last mission for one update time is terminated, a new update time is computed and another set of missions is run. Finally, when the last update time has been tested, the simulation is terminated.

Conclusion

After integrating the aircraft mission and target movement into one simulation model, computer runs can be made to generate the desired results. Timing is very important throughout the simulation to ensure the results are as realistic as possible. However, one thing to keep in mind is that the simulation may not exactly match the real world. An exact match is virtually impossible to achieve. A simulation model is only as good as the inputs into the model and the assumptions made while building the model. Verification and validation of the model is very important if the output from the computer runs is to be of any use. Chapter 5 discusses how the verification and validation stages were accomplished.

V. Verification and Validation

Introduction

Computers in general do not make mistakes; people (programmers) make mistakes. Simulation models are not worth the time and effort to run if the model is not a reasonable representation of the real world. Verification and validation of the computer model are required if the model is to provide any useful information to a decision maker.

Chapter 5 discusses the verification and validation stages of this simulation model. Verification is accomplished by comparing the model output to manual calculations for a small example mission. To validate the model, input values are varied and changes in the final results are compared to expected values based on knowledge and past experience of the SRT missions.

Verification

Verification of the model consists of determining that the model executes as intended (9:12). For the target movement, an output trace of all grid locations which the target occupies and the times of occupation are output. A close look at the data indicates if moves are being made in all directions acording to the uniform distribution assigned and if the moves occur at the proper times. Also, a check is made to see if other location restrictions are being observed.

To verify the aircraft mission, a comparison is made between the results from manual calculations for the matrix operations and the computer output to ensure the program is doing the calculations correctly. Moreover, checking the simulation time of certain events throughout the aircraft mission shows if appropriate delays are being integrated with the target movement. Output of an example using a square search area divided into nine total grids (target locations) will show the desired results to verify the model (Fig 5.1).

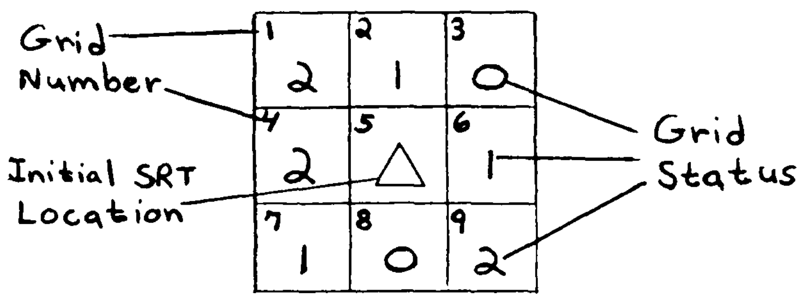


Fig. 5.1. Search Area Used to Verify and Validate the Model

Target Model. To be consistent, the target is modeled to start every mission in the same grid. As stated earlier, each target is assigned to an MOB (Main Operating Base) with the center grid of the search area containing the MOB (Fig. 5.1). Before each mission begins, the center grid is computed from the other input data and the SRT is established in that grid. Using the present example, the output shows the target starting in grid 5 (center grid) for every mission which confirms the calculation is being done correctly.

Once initialized to the proper starting point, random movement can then begin.

Target movement is modeled to be evenly distributed in all possible directions. Because only a small number of missions were simulated for verification purposes, the percentage of time each direction was chosen will not be a very accurate estimate of the distribution. However, other indications show all possible directions are being used. Tracing the target's location shows that each grid is selected as a new location several times during the short simulation. Over many runs, each direction should be chosen an approximately equal number of times. However, other location restrictions prevent some grids from being selected as many times as they otherwise would.

Each grid's status will determine if a grid can be entered or not and could also prevent surrounding grids from being selected as often. As a new grid is selected, specific output statements are printed to show the grid's status. A trace of the target movement indicates the location restrictions are being observed in the present example; only grids with a status of 2 have targets setting up, grids with a status of 1 are being entered with no dwelling, and grids with a status of 0 are not entered at all. Since grids 3 and 8 (fig. 5.1) have a status of 0, grids 6 and 9 are selected less often than other grids because more movement can take place in the opposite corner (grids 1, 2, 4, and 5). However, all grids are being selected at some point

regardless of the other location restrictions which leaves only the timing of the moves to be checked.

Based on the input values for target speed and dwell times, target moves can be manually checked for correct timing. SRT's start the simulation (time 0) in the center grid. For this example, 0.5 miles per minute is used as the target speed, 90 minutes as the dwell time, and 17.6 miles as the grid size. Initially the target should only move halfway across the center grid (no dwell time for the first move). This is being done properly in the model as confirmed from the sample output showing grid 1 (the first new location, second grid) being entered at 34.8 simulated minutes. Next, a move is made to grid 4 at time 194.4. Manual calculations confirm that with 90 minutes of dwell time and 34.8 minutes to move halfway across one grid, 194.4 is the correct time to enter the third grid. Repetitions of the direction selection and corresponding moves continue throughout the simulation run and all times are calculated correctly.

Verification of the target model is now complete. Random directions are being chosen, location restrictions are being observed, and timing is being simulated properly. However, for the simulation results to be of value, the aircraft model must also be verified.

Aircraft Model. Verification of the aircraft model must start by ensuring appropriate delays are accounted for

before the first aircraft event (takeoff or intelligence update). Depending on the input information, the aircrew can receive the intelligence update either before or after takeoff but the search still begins at the same simulated time (when the aircraft enters the search area) every mission. Comparing runs with updates before takeoff with runs having the update after takeoff reveals the same time of 860.0 simulated minutes as the time the search begins for the first mission of each run. Since random numbers play a part in some delays, the start of the search for the first mission of future runs will not be the same. However, by checking the time each subsequent mission starts and adding the scheduled delays from time zero to the time the search starts (860.0 for this example), the time the search begins can be confirmed.

For example, mission number 1 in run number 1 began at time 0 and started the search at time 860.0. A second mission started when all entities for the first mission were destroyed. This occurred at time 902.4. Therefore, the search in the second mission should begin at time 1762.4 (860.0 + 902.4). Since output from the example confirms the time, correct calculations again are being done.

For mission number 1 in run number 2, the times were the same as before except for the ending time. Because of randomness in some delays, the first mission ended at time 870.0 (vs 902.4). Adding 860.0 to 870.0 indicates the search for the second mission should begin at time 1730.0

which is also confirmed by the output information. Even though the times are slightly different, the appropriate delays up to the aircraft search time are being handled correctly. But even though the search starts at the correct time, the aircrew must also have the correct information in order to search for the target properly.

Updated information must be given to the aircrew at the appropriate time if future calculations are to be correct. If an 80 minute update is being tested, the aircrew should know the location of the SRT 80 minutes before the search begins. Comparing the target movement trace to the output of the aircraft model reveals that in all cases correct information is received by the aircrew.

As an example, in mission number 1 of run 1, an 80 minute update is expected with the search to begin at 860.0. Manual calculations show that at time of 780.0 the aircrew should receive the intelligence update on the target's actual location. Target output shows the target location as grid 1 at time 780.0. The aircraft model output confirms the aircrew received information that the target was in grid 1 at the 80 minute update. This thought process can be done for all missions and the results are confirmed in all cases. However, getting the correct grid number at the correct time to the aircrew is only part of the updated information required to start the search.

Matrix operations to compute the unconditional probability distribution of the target's location must be done before the aircraft search begins. Computing the unconditional probabilities requires the initial position (or position at the update time) and the n-step transition matrix. If no move can be made by the target between the time the update is received by the aircrew and the time the search begins, the grid number passed in the intelligence update will be the only grid searched. If one or more moves are possible, the one-step transition matrix must be raised to a power equal to the estimated number of moves. Multiplying the n-step transition matrix times the initial position vector results in the desired unconditional probabilities. Verification of these operations can be done as before by comparing manual calculations with the computer output resulting from the aircraft search.

Sorting the grid number by unconditional probability from highest to lowest results in a ready made ordered list of grids for the aircraft to search. After computing the unconditional probabilities, a sort routine is used to develop the ordered list. Aircraft will then enter the first grid number on the list to check for the target. If the target is not found, the next grid on the list is checked only if the unconditional probability for target presence is greater than 0. The search continues in this fashion until the target is found or the allotted search time runs out. Output information from the aircraft model indicates that

not only are the calculations for the updated information being done correctly but the search is also being done as intended. First a look at the update calculations.

From mission number 1 of run number 1, the sorted target location distribution is as follows:

Grid Number	Prob. of Target Presence	
4	0.5	
5	0.5	
1	0.0	
2	0.0	
3	0.0	(5)
6	0.0	
7	0.0	
8	0.0	
9	0.0	

Since an 80 minute update is used, the target is estimated to be able to make only one move after the update is received by the aircrew and before the search begins (Assuming the SRT has been in place for half of its allotted time, the target should move in 159.6/2 or 79.8 minutes which is less than 80 minutes). Therefore, the one-step transition matrix should be raised to the first power and multiplied times the position vector for grid 1 (the location of the target at the update time). Results should reveal the first row of the one-step transition matrix. After sorting from highest to lowest unconditional probablity, the results are exactly as expected. However, this case shows the sorting routine worked but does not indicate if the matrix multiplication routine works because the one-step transition matrix required no changes from the input values.

Using a 240 minute update in run number 3, two moves are possible by the target from the time of the update until the search begins. When the update is received, the assumption that the target has spent half the total time in the current grid equates to a grid change at time 79.8. After dwelling and moving through the second grid (using 159.6 minutes), the third grid will be entered at an estimated time of 239.4. Since the two moves will be made in 239.4 minutes and the aircraft will not arrive until 240 minutes after the update, the one-step transition matrix must be squared.

Results from mission number 1 on run number 3 are as follows:

Grid Number	Prob of Target Presence	
5	0.65	
1	0.20	
4	0.15	
2	0.0	
3	0.0	(6)
6	0.0	
7	0.0	
8	0.0	
9	0.0	

For this mission, the target was observed in grid 5 at the update time. Therefore, the expectation would be that the fifth row of the two-step transition matrix (sorted) would be output. Manual calculations result in the following for the two step transition matrix:

$$P^{(2)} = \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \left[\begin{array}{ccccccccc} .40 & 0 & 0 & .20 & .25 & 0 & 0 & 0 & .15 \\ .29 & 0 & 0 & .12 & .50 & 0 & 0 & 0 & .09 \\ 0 & 0 & 1.0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .15 & 0 & 0 & .45 & .25 & 0 & 0 & 0 & .15 \\ .20 & 0 & 0 & .15 & .65 & 0 & 0 & 0 & 0 \\ \hline .15 & 0 & 0 & .20 & .50 & 0 & 0 & 0 & .15 \\ .40 & 0 & 0 & .20 & .25 & 0 & 0 & 0 & .15 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0 & 0 \\ .30 & 0 & 0 & .40 & 0 & 0 & 0 & 0 & .30 \end{array} \right] \end{array} \qquad (7)$$

Row number five, after being sorted, produces the same results as the program's calculations. Checks of other missions also show that the computations and sorting are being performed correctly. However, given the aircrew has the correct information, a check must be done to see it the search is being done as intended.

Comparing the sorted unconditional probability list with the actual grids searched by the aircraft verifies that the aircraft is searching the correct grids in the right order. From mission 10 of run number 2 (a random choice), results are the following:

<u>Target Location Distribution</u>:

Grid Number	Prob. of Target Presence
4	0.4
1	0.3
9	0.3
2	0.0
3	0.0
5	0.0
6	0.0
7	0.0
8	0.0

(8)

Aircraft Search:

Grid Searched

4
1 (9)
9

Since three grids can be searched in the allotted time, only the first three grids on the sorted list were searched and in the proper order. A question that comes to mind is which grid would be searched next if four grids could be searched.

Rather than search a grid that is estimated to have a 0 probability of containing the target, the search reverts to the top of the list when a probability of zero is encountered. In the mission described above, since the next grid (grid 2) has a probability of zero of target presence, grid 4, at the top of the list, should be revisited. Another mission illustrates the handling of this type of situation.

Returning to mission number 1 of run number 1, the search returned to the first grid on the sorted list rather than search a grid with a 0 probability of target presence. Grids 4 and 5 were searched first because each had a probability of 0.5 of containing the target. However, all other grids were estimated to have a probability of zero of containing the target. Therefore, after searching grid 5 with no detection, the third grid searched was 4 again rather than 1. Output information from the run is as follows:

Target Location Distribution:

Grid Number	Prob. of Target Presence	
4	0.5	
5	0.5	
1	0.0	
2	0.0	
3	0.0	(10)
6	0.0	
7	0.0	
8	0.0	
9	0.0	

Aircraft Search:

Grid Searched	Time Search Began	
4	860.0	
5	862.9	(11)
4	865.8	

In the last example, note also the time delays between searching each grid. Based on the input speed of the aircraft and the grid size, a specific time should be spent searching each grid. With a speed of 6 miles per minute and 17.4 miles across each grid as in the present example, each search should take 2.9 minutes. Confirmation can be made by computing the difference between the start of each consecutive search (865.8 - 862.9 = 2.9). With this check, verification of the aircraft model is complete except for one final point. What happens when the target moves during the search?

If a target move is anticipated during the search, some adjustments must be made. First, the current n-step transition matrix must be multiplied by the one-step transition matrix one more time to form the (n+1)-step transition matrix. Next, the new unconditional probability distribu-

tion must be calculated using the location confirmed at the update time. Finally, after sorting the probability distribution, the search continues in the first grid on the new sorted list. However, one critical point at this stage is that the search time used by the aircraft is cumulative. A new search does not start. The same search continues using the new sorted list. If two grids were already searched and time only allows a total of three to be searched, only one grid can be searched from the new list. Verification of the model in these circumstances is accomplished using the same comparisons as before.

Another example run with an 180 minute update gave the following results (target was in grid 5 at the update time):

Initial Location Distribution:

Grid Number	Prob. of Target Presence	
4	0.4	
1	0.3	
9	0.3	
2	0.0	
3	0.0	(12)
5	0.0	
6	0.0	
7	0.0	
8	0.0	

After the move the new location distribution was:

Grid Number	Prob. of Target Presence	
5	0.65	
1	0.2	
4	0.15	
2	0.0	
3	0.0	(13)
6	0.0	
7	0.0	
8	0.0	
9	0.0	

Aircraft Searched:

Grid Searched

4
5 (14)
1

Manual calculations confirmed that in both cases the printed list of the unconditional probabilities was the fifth row of the respective transition matrix. The search pattern shows a move by the target was anticipated while the aircraft was searching grid 4 (the first grid on the initial location distribution). Therefore, the search continued after the first grid was searched but started using the new sorted list (grid 5). Also, in the end only three grids were searched, with one using the initial location distribution and two using the updated list. With these results the verification stage is complete.

Verification of the target model and aircraft model ensures the simulation is operating as intended. However, the results still are not very valuable if the model is not a reasonable representation of the system being simulated. Validation of the model will confirm this representation.

Validation

Validation of a simulation model is normally performed at various levels (9:12). Alan B. Fritsker, in his book "Introduction to Simulation and SLAM II" (9), recommends performing validation on the data inputs, model elements, subsystems and interface points (9:12). In each case, a

comparison of the model and system is done as a test for reasonableness (9:13). Past system outputs and knowledge of system performance behavior based on experience should be used as yardsticks for the comparison (9:13).

Data Inputs. Information concerning strategic relocatable targets is classified. Characteristics such as dwell time, set up time, tear down time, and possible setup locations are all available but only in classified form and cannot be addressed in an unclassified project. For verification, notional or sample numbers in the range of actual values can be used. However, results that are output from the model using the notional numbers cannot be used for validity checks since experience with SRT missions is limited. But, the results can be used by doing some sensitivity analysis with various input values in conjunction with the validation of the model elements.

Model Elements. As with the data inputs, the output from the computer program will not validate the model elements but can indicate a reasonable representation of the real world by way of some sensitivity analysis. Outputs from past systems are not available because the area of SRT's is still quite new. However, assessments can be made about the reasonableness of the model by varying the input values and observing the changes in the results (9:13). Variations in four factors were observed.

First, the grid size was varied. In all cases, the probability of finding the target was lower or unchanged

when the grid size was increased. Since more area has to be covered with the larger grid size, this is a logical result. Aircraft search time is limited and if more time is spent searching one grid, less time remains to search other grids. Also, a larger grid size allows more room for the target to hide. Therefore, responses to changes in grid size appear valid.

Search time is the second factor varied. As would be expected, given more search time an increase in the probability of finding the target is observed. If more grids can be searched, chances are better of finding the SRT.

Third, the time unit of the stochastic process is changed. The time unit is the total time an SRT spends in one grid (including dwell time, set up time, tear down time and moving time). For this variation, the pattern was not as obvious. However, the overall indication is that as the time unit is increased (SRT spends more time in one location), the probability of detection also increases. Again a logical conclusion.

Finally, the fourth factor to be varied is the aircraft sensor system detection factor. Logically, as sensor systems improve, the chance of finding the target with them should be better. In each case, the model output showed an increased or unchanged probability of detection indicating again the correct sensitivity of the model to various inputs.

Subsystems and Interface Points. Validation of the subsystems and interface points has really already been addressed as they pertain to this model. Each subsystem of the model involved specific calculations which have already been verified. Also, in verfifying the model, the timing of events was shown to be correct. Each event in the SLAM model called the appropriate FORTRAN subroutines at the proper time to perform the required actions. Validation of the interface between SLAM and FORTRAN, as well as between the target and aircraft models is complete due to the verification of the timing and validation of the model elements.

Conclusion

Verification and validation of a model are necessary stages of model building. Verification proves the model does what is intended. Validation goes one step farther to ensure what is intended is a reasonable representation of the real world system being simulated. Verification was accomplished in this model by comparisons with manual calculations using a small example. Validation was difficult because of no past data. However, a sensitivity analysis on the inputs into the model indicated the results shifted in logical directions as specific factors were varied. The numbers themselves were not important since only notional numbers were input. But what is important is that the directions the probability of detection moved as the inputs

varied are logical and give a good indication of the validity of the model.

A primary purpose of this project was to build a simulation model for an SRT mission; but this is not the end. With a valid model, large examples can be run and further analysis can be accomplished on the results. Even more, the value of the output information and how the information can be used will be investigated in the final chapters.

VI. Experimentation and Results

Introduction

A representative SRT mission was simulated to demonstrate how this model can be used. To keep the thesis unclassified, sample numbers within the range of actual values were input. Subsequent analysis on the output of the simulation runs using the sample inputs illustrates how the model could be adequately used in a classified environment.

Chapter 6 first describes the factorial design used for initial screening of the factors. Analysis of the results follows to indicate which factors or interaction effects are considered significant. Using the results of the factorial design, final "production" runs are conducted and their results analyzed.

Experimental Design

Many experiments involve the study of the effects of two or more factors on a desired result. A factorial design has been found to be most efficient in analyzing these effects (7:189). All combinations of the factors involved are tested at each of their possible values and the effect on the overall result is measured in each case.

Determination of Factors. Before the design can be run, the factors to be tested must be determined. Any factor (variable, input value) that can change the output value should be considered. For the SRT mission, all the

variables were reduced to four factors that can affect the desired result: grid size, allotted search time, time unit of the stochastic process, and the conditional detection probability.

Grid size is a combination of the search radius of the aircraft and the altitude flown. The search radius is how far the aircraft sensors can "see" ahead of the aircraft (anywhere from 90° to the left through 90° to the right). Changing altitude changes the distance the aircraft can see. To ensure the aircraft can scan an entire grid as it flies straight through the grid's center, a grid size twice that of the search radius is used. Therefore, from the center-line of the grid, looking left or right will enable the sensors to see all the area included in the grid. Because grid size and search radius are proportional to one another, only grid size will be considered as a factor.

Imbedded in the second factor, allotted search time, is the speed of the aircraft. Search time is how much time the aircraft has to search for the SRT. Faster flying aircraft can search more area in the allotted time than slower aircraft. Changes in the model's result due to increased/decreased search time can indicate an effect due to a change in the aircraft's speed or a change in search time. Again both factors are proportional and can be tested for significance by considering just the search time.

A third factor is the time unit of the stochastic process (time between changes in the SRT's location). As in the other two factors, the time unit is determined by a combination of other variables such as dwell time, speed of the SRT, and the average distance per move by the SRT. Changing any one or a combination of these variables changes the time between new locations for the SRT. For instance, since the grid size is constant, a faster speed by the SRT means less time is spent in one grid whereas a longer dwell time means a longer time. Because these variables directly affect the time unit used, only the time unit needs to be considered over its possible range of values. Changes in the time unit can be made by changing any one of the imbedded variables with the subsequent analysis indicating whether the factor caused a significant change in the final result.

Finally, the fourth factor is the conditonal detection probability. As referred to here, the detection probability is the probability the aircraft detects the target given the sensors are looking directly at the SRT and is computed as the product of two other factors. Multiplying the target detection factor by the aircraft sensor system detection factor results in the conditional detection probability (14:slide 10). Therefore, this probability is computed and input into the model as a constant to be used for all runs. So while it is a probability, it remains a constant factor for one set of input data. Varying the conditional detec-

tion probability over its possible range will indicate its significance as well as the significance of the other two given factors.

Screening Runs. Usually initial screening runs in a design will indicate which factors have a significant effect on the results and which factors can be disregarded due to their lack of significance. However, the structure of the SRT problem is slightly different. Rather than determine which factors or interactions are significant at one update time, a relationship between each update time is desired to determine if any factors or interactions change in significance as the update time changes.

Three update times were chosen. Since significant changes in the overall detection probability will more than likely occur for shorter update times than for longer update times, 80 minutes, 160 minutes, and 240 minutes were chosen for the screening runs. These times should cover the range of time where significant changes in the results should occur.

To complete the screening runs, a 2^4 factorial design with three replicates at each treatment level is accomplished. Each of the four factors is considered at two levels as defined in Table 6.1. Sixteen total runs is required to complete one replicate of the design. For this model, a complete design was accomplished three times for each of the three updates resulting in a total of 48 runs at

TABLE 6.1

List of Factors

Letter	Factor	Low	High
A	Grid Size	17.4 miles	38.8 miles
B	Search Time	21 min	46 min
C	Time Unit	34.8 min	276.24 min
D	Detection Prob.	0.5	1.0

each update time. But to determine the significance of these factors on the probability of detecting the SRT, a model to estimate the probability must also be developed.

To estimate the probability of the aircraft finding an SRT, the percent of successes for all missions flown is used. Estimating the probability of detection is a binomial experiment. A binomial experiment is a sequence of identical and independent runs which can result in only one of two possible outcomes (6:78). Each mission flown results in a hit (1) or a miss (0). The target parameter, p, can be estimated by Y/n where Y is the number of hits and n is the total number of missions flown at one update time (6:297). For each run, the number of hits, Y, is computed but the value of n is still needed to ensure the estimate is within a specified accuracy.

By specifying a maximum variance and significance level, the value of n can be computed. To be 95% sure that the estimate computed is within .1 of the actual probability, 95% of the estimates must lie within two standard deviations of the actual probability with repeated computer runs (6:317). In other words

$$2\sigma_p = .1 \quad (15)$$

but $$\sigma^2_p = p(1-p)/n \quad (16)$$

therefore $$2(p(1-p))^{1/2}/n^{1/2} = .1 \quad (17)$$

and $$n = 4(p)(1-p)/.01 \quad (18)$$

A value for p must be estimated to calculate an appropriate value for n. Assuming p=.5 represents the worst possible case and results in the largest value of n

$$n = 4(.5)(.5)/.01 = 100 \quad (19)$$

As a result, 100 missions were flown to estimate the probability of finding the target at a given update time. (Note: If .01 were used as the variance, 1000 runs would be required for the desired accuaracy and 100 runs were considered sufficient for this problem to demonstrate the model output).

Table 6.2 indicates the actual combination of factors that was used for the 16 computer runs in the design and the results of each run. To read the chart, the column labeled "Treatment" shows which combination of factors was used for that run. A lower case letter indicates that particular factor was set at its highest value for the run. The absence of a letter indicates the factor was set at its lowest value. A (1) indicates all factors were set at their lowest values. Results for each of the three replicates are listed under the respective update time and run number. To eliminate some random error, random number streams were changed for each replicate (called blocking on the random number stream)(7:123).

TABLE 6.2

Treatment Levels and Results

	Probability of Detection Estimate								
	80 min update			160 min update			240 min update		
Treatment	1	2	3	1	2	3	1	2	3
(1)	.30	.30	.19	.21	.24	.19	.10	.19	.25
a	.22	.31	.20	.23	.12	.13	.21	.13	.07
b	.41	.49	.36	.31	.41	.39	.31	.33	.37
ab	.44	.34	.31	.28	.26	.24	.26	.25	.25
c	.08	.06	.07	.27	.28	.21	.32	.38	.36
ac	.01	.00	.00	.20	.16	.11	.20	.23	.15
bc	.10	.06	.10	.28	.36	.28	.38	.44	.42
abc	.09	.07	.08	.29	.27	.27	.32	.31	.35
d	.52	.51	.47	.42	.48	.46	.33	.37	.43
ad	.36	.38	.38	.30	.23	.37	.33	.22	.24
bd	.77	.76	.73	.59	.69	.75	.45	.52	.57
abd	.56	.63	.58	.44	.40	.57	.47	.47	.47
cd	.11	.08	.11	.42	.35	.28	.43	.48	.41
acd	.01	.00	.00	.37	.32	.26	.29	.39	.36
bcd	.11	.08	.11	.42	.35	.28	.43	.48	.41
abcd	.11	.08	.11	.42	.35	.28	.43	.48	.41

The algebraic signs used to calculate the effects of the four factors is displayed in Table 6.3 with the respective ANOVA Tables for the three update times shown in Tables 6.4, 6.5, and 6.6. While definite conclusions may be hard to draw from the results, some general inferences can be made.

TABLE 6.3

Algebraic Signs for Calculating Effects of Factors

Treatment	A	B	AB	C	AC	BC	ABC	D	AD	BD	ABD	CD	ACD	BCD	ABCD
(1)	−	−	+	−	+	+	−	−	+	+	−	+	−	−	+
a	+	−	−	−	−	+	+	−	−	+	+	+	+	−	−
b	−	+	−	−	+	−	+	−	+	−	+	+	−	+	−
ab	+	+	+	−	−	−	−	−	−	−	−	+	+	+	+
c	−	−	+	+	−	−	+	−	+	+	−	−	+	+	−
ac	+	−	−	+	+	−	−	−	−	+	+	−	−	+	+
bc	−	+	−	+	−	+	−	−	+	−	+	−	+	−	+
abc	+	+	+	+	+	+	+	−	−	−	−	−	−	−	−
d	−	−	+	−	+	+	−	+	−	−	+	−	+	+	−
ad	+	−	−	−	−	+	+	+	+	−	−	−	−	+	+
bd	−	+	−	−	+	−	+	+	−	+	−	−	+	−	+
abd	+	+	+	−	−	−	−	+	+	+	+	−	−	−	−
cd	−	−	+	+	−	−	+	+	−	−	+	+	−	−	+
acd	+	−	−	+	+	−	−	+	+	−	−	+	+	−	−
bcd	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
abcd	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

TABLE 6.4

ANOVA Table for the 80 Minute Update

Source of Variation	SS	df	MS	F[a]
Grid Size (A)	.054	1	.054	41.84[a]
Search Time (B)	.1645	1	.1645	127.46[a]
Time Unit (C)	1.6465	1	1.6465	1275.74[a]
Detect Prob (D)	.1838	1	.1838	142.39[a]
AB	.0013	1	.0013	1.012
AC	.0073	1	.0073	5.62[b]
AD	.0105	1	.0105	8.138[a]
BC	.0581	1	.0581	45.025[a]
BD	.0073	1	.0073	5.62[b]
CD	.1398	1	.1398	108.28[a]
ABC	.0099	1	.0099	7.677[a]
ABD	.0002	1	.0002	.193
ACD	.0068	1	.0068	5.242[c]
BCD	.0068	1	.0068	5.24[c]
ABCD	.0003	1	.0003	.202
Error	.0413	32	.0013	
Total	2.3387	47		

[a] Significant at 1 percent

[b] Significant at 2.5 percent

[c] Significant at 5 percent

TABLE 6.5

ANOVA Table for the 160 Minute Update

Source of Variation	SS	df	MS	F°
Grid Size (A)	.0876	1	.0876	27.324[a]
Search Time (B)	.1376	1	.1376	42.94[a]
Time Unit (C)	.0554	1	.0554	17.265[a]
Detect Prob (D)	.3024	1	.3024	94.383[a]
AB	.00002	1	.00002	.0065
AC	.0248	1	.0248	7.725[a]
AD	.0020	1	.0020	.625
BC	.0369	1	.0369	11.50[a]
BD	.000004	1	.000004	.00128
CD	.0514	1	.0514	16.03[a]
ABC	.0083	1	.0083	2.58
ABD	.0002	1	.0002	.052
ACD	.0158	1	.0158	4.921[b]
BCD	.0144	1	.0144	4.48[b]
ABCD	.0003	1	.0003	.079
Error	.1025	32	.0032	
Total	.8395	47		

[a] Significant at 1 percent

[b] Significant at 5 percent

TABLE 6.6

ANOVA Table for the 240 Minute Update

Source of Variation	SS	df	MS	F°
Grid Size (A)	.0729	1	.0729	36.83[a]
Search Time (B)	.1530	1	.1530	77.35[a]
Time Unit (C)	.0336	1	.0336	16.98[a]
Detect Prob (D)	.2255	1	.2255	113.997[a]
AB	.0073	1	.0073	3.668[b]
AC	.0006	1	.0006	.3065
AD	.0029	1	.0029	1.444
BC	.0204	1	.0204	10.324[a]
BD	.0002	1	.0002	.0874
CD	.0213	1	.0213	10.75[a]
ABC	.0035	1	.0035	1.767
ABD	.0032	1	.0032	1.599
ACD	.0063	1	.0063	3.183[b]
BCD	.0054	1	.0054	2.736
ABCD	.0015	1	.0015	.772
Error	.0633	32	.0012	
Total	.6207	47		

[a] Significant at 1 percent

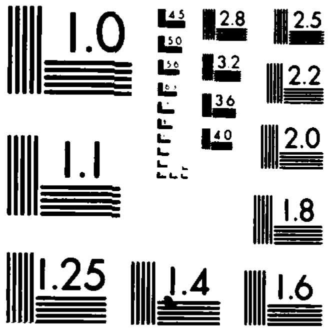
[b] Significant at 10 percent

Analysis of Screening Runs. For each of the three update times selected, all four main effects (effects due only to one factor) caused significant changes in the result (7:189). Using the magnitude of the resulting F test as an indication of significance, the order of the four factors from most significant to least significant is the conditional detection probability, allotted search time, grid size, and the time unit of the stochastic process. Although all four factors are significant, if tradeoffs are required, a decision maker may be able to use the general inferences just stated to make a future decision. Even more helpful however, may be the inferences that can be made from the interaction effects.

Only interaction effects involving two factors indicated a significant change in the resulting probability estimate. Any interaction effect involving the grid size (A) was not found to be significant On the other hand, the time unit of the process (C) was found to be significant when combined with either the allotted search time (B) or the conditional detection probability (D). Since B and D individually seemed to be the most significant, the combined significance was probably due more to just the effects of B and D with C s effects relatively insignificant.

Results of this design do not indicate which factors are necessarily more significant than the others but the results can indicate which factors may need emphasis if tradeoffs must be made. Primarily, the results extracted

AD-A172 526 HOW THE TIMING OF UPDATES ON THE LOCATION OF STRATEGIC 2/2
RELOCATABLE TARGET..(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. D B OLYNICK
UNCLASSIFIED DEC 85 AFIT/GOR/ENS/85D-15 F/G 15/7 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

are two fold. First, all main effects are significant. Second, each main effect is significant at all update times in the range tested. If a decision maker has to decide between a change in two factors such as aircraft altitude (grid size) and sensors to use for the search (conditional detection probability), results from this design can steer the decision maker in the right direction. Knowledge of the significant factors and interaction effects allows an input data set to be built for use in the "production" runs to demonstrate the usefulness of the model.

Production Runs

To demonstrate the final output, an example SRT mission is simulated. All variables are set to realistic values to simulate an actual mission. The values remain the same for all computer runs. Initially, 100 missions are simulated with the aircrew receiving an intelligence update 30 minutes prior to entering the search area. The number of hits (divided by 100) is used as the estimate for the probability of detection for that update time. A plot is started using this result as the first data point.

Continuing, another 100 missions are flown with a 60 minute update and the process repeated as before. Each subsequent run has the aircrews receiving an update 30 minutes earlier than the previous set of aircrews. After the 16th run representing an eight hour update, a one hour increment is used between runs for the final eight runs. A

total of 24 runs are made covering a range of update times from 30 minutes to 960 minutes (16 hours). The table of results is shown in Table 6.7 with the plot of all update times and the respective detection probabilities shown in Fig. 6.1. At this point a decision maker would have some valuable information to help utilize his intelligence resources. However, since this plot is only good for this set of input data, a new plot has to be generated for each different mission.

TABLE 6.7

Table of Example Results

Run	Update (min)	Detect Prob
1	30	.92
2	60	.90
3	90	.46
4	120	.52
5	150	.58
6	180	.47
7	210	.44
8	240	.49
9	270	.49
10	300	.47
11	330	.42
12	360	.40
13	390	.40
14	420	.47
15	450	.43
16	480	.43
17	540	.36
18	600	.31
19	660	.32
20	720	.27
21	780	.28
22	840	.33
23	900	.32
24	960	.36

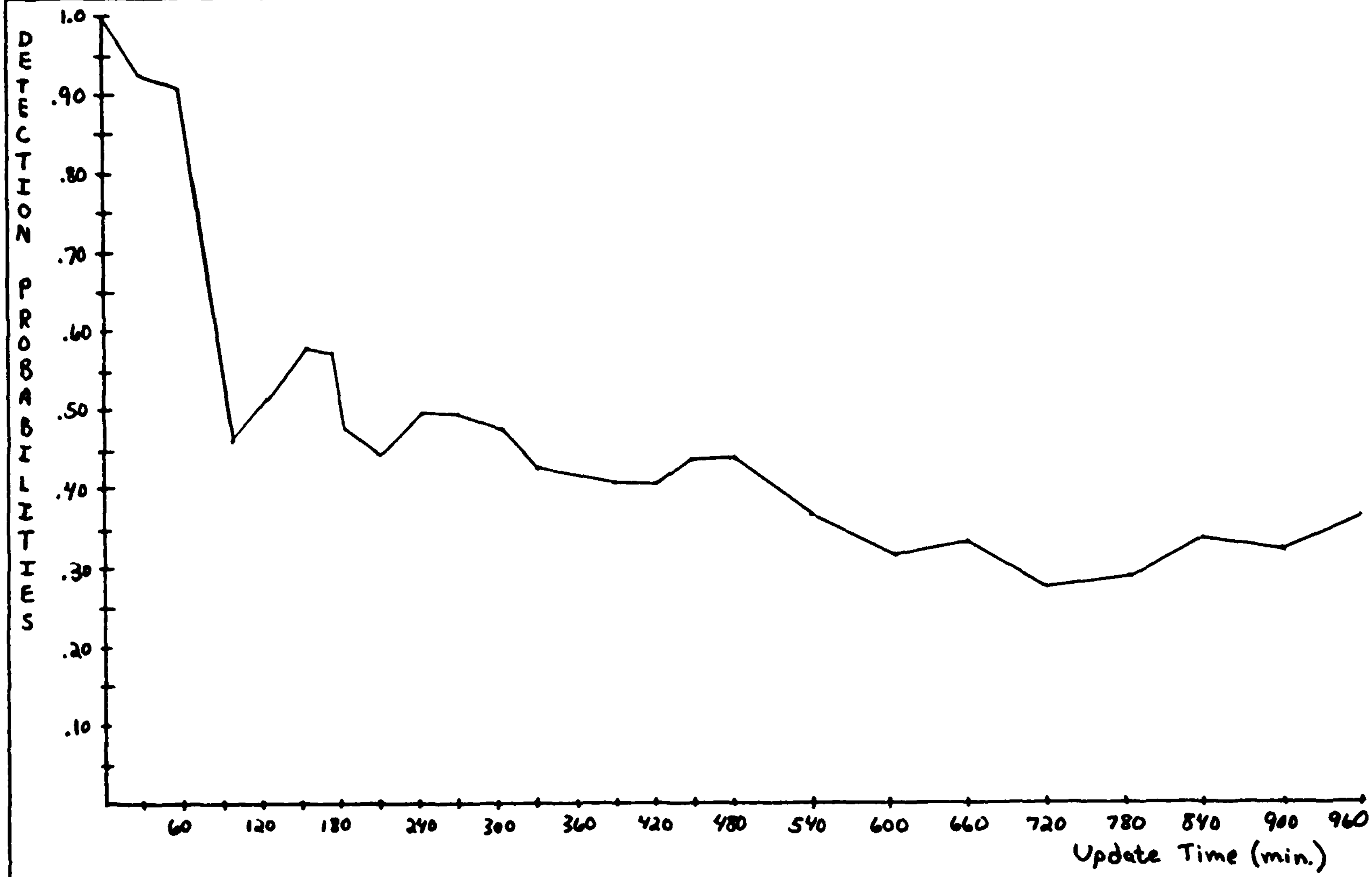


Fig. 6.1. Plot of Detection Probabilities vs Update Times

Developing the Confidence Bands

For each run, the percentage of hits out of 100 missions was plotted against the update time corresponding to the run. However, as a further step, a confidence band was drawn around the estimated probabilities to better indicate the desired relationship.

To obtain a confidence band around the computed curve, the Bonferroni approach was used. A confidence interval for each estimate is constructed and each point plotted on the same graph with the estimated probabilities. By connecting the points both above and below the original plot, a "confidence band" will result. However, the accuracy of the band and inferences that can be made depend on the confidence coefficient chosen and the number of confidence intervals in the "family" (how many estimates are involved).

Each confidence interval was built using a confidence coefficient (α) of .01 which means 99% of the intervals computed at each update time will include the actual parameter value (actual detection probability) for that update time (8:707). Overall, since each run is independent, the confidence coefficient is $(1-\alpha)^g$ where α is the confidence coefficient for one interval and g is the number of estimates (8:150). Therefore, the computed confidence coefficient is:

$$(1-\alpha)^g = (1-.01)^{24} \approx .79 \qquad (20)$$

Bonferroni confidence intervals are constructed using the following formula(8:158):

$$\hat{y}_h \pm Bs(\hat{y}_h) \qquad (21)$$

where: $\hat{y}_h$ is the estimated probability

B is the Bonferroni constant ($B=t(1-\alpha/2g;n-2)$)

g is the number of confidence intervals

h is the sample size

$s(\hat{y}_h)$ is the standard deviation of the estimate ($\sigma^2_p = p(1-p)/n$)

The results of each calculation is shown in Table 6.8 along with the previous results and the confidence band is plotted on the graph with the estimated probabilities in Fig. 6.2.

TABLE 6.8

Example Problem Results With Confidence Interval Calculations

Run	Update (min)	Detect Prob	$s(\hat{y}_h)$	B=3.405 $B(s(\hat{y}_h))$	Limits Lower	Limits Upper
1	30	.92	.027	.092	.828	1.012
2	60	.90	.030	.102	.798	1.002
3	90	.46	.050	.170	.290	.630
4	120	.52	.050	.170	.350	.690
5	150	.58	.049	.167	.413	.747
6	180	.47	.050	.170	.300	.640
7	210	.44	.050	.170	.270	.610
8	240	.49	.050	.170	.320	.660
9	270	.49	.050	.170	.320	.660
10	300	.47	.050	.170	.300	.640
11	330	.42	.049	.167	.253	.587
12	360	.40	.049	.167	.233	.567
13	390	.40	.049	.167	.233	.567
14	420	.47	.050	.170	.300	.640
15	450	.43	.050	.170	.260	.600
16	480	.43	.050	.170	.260	.600
17	540	.36	.048	.163	.197	.523
18	600	.31	.046	.157	.153	.467
19	660	.32	.047	.160	.160	.480
20	720	.27	.044	.150	.120	.420
21	780	.28	.045	.153	.127	.433
22	840	.33	.047	.160	.170	.490
23	900	.32	.047	.160	.160	.480
24	960	.36	.048	.163	.197	.523

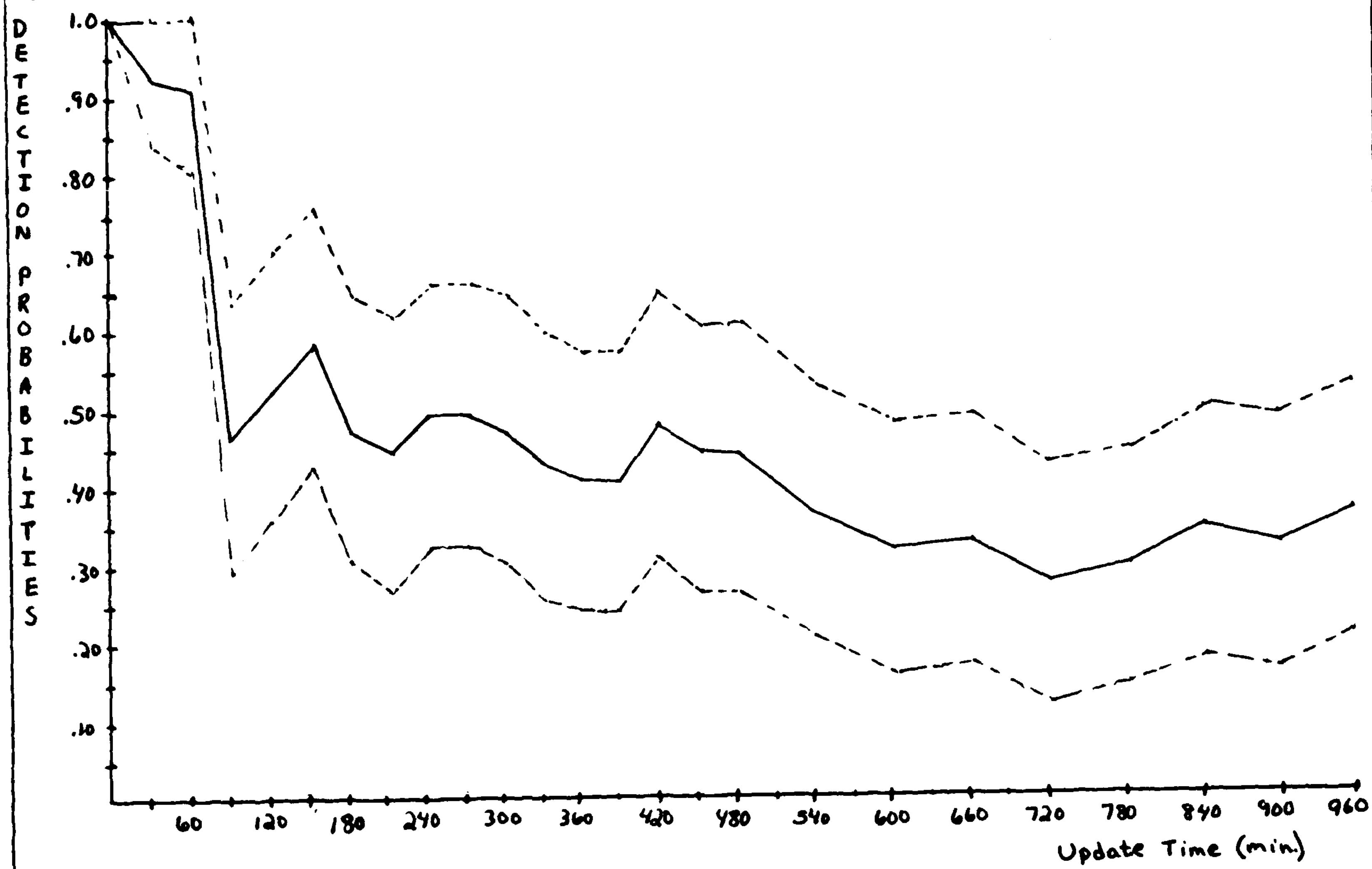


Fig. 6.2. Plot of Detection Probabilities vs Update Times with Confidence Bands

Interpreting the Plot

Before the project was undertaken, a generally accepted thesis was that the closer the aircraft is to the target when the update is received, the better the chance of finding the target. Results from the example run are in line with this thinking. However, as questioned earlier, how "close" should the update be to the aircraft arrival time to produce an acceptable detection probability.

Updates at 30 minutes and 60 minutes resulted in much higher detection probabilities (by more than .30) than any other point on the plot. As it turns out the input data used required 69.6 minutes for the SRT to move half way through one grid. Also, besides the move time, 90 minutes of dwell time was required. Therefore, an SRT spent 159.8 minutes in grids that allowed stops. Since the aircraft does not know how long the SRT has been in the grid location reported at the update time, the assumption made earlier in Chapter 4 is that half of the total possible time has been spent in the reported location. Based on this assumption, 79.8 minutes was used in every aircraft mission throughout the example. Both the 30 and 60 minute updates are less than the assumed time which means the aircraft assumes the target cannot move before the search begins. When a 90 minute update (or earlier) is received, one or more moves will be assumed by the aircraft and the results show a significant drop in the probability of detection for that

particular update time. Something significant happens between the 60 and 90 minute updates.

From this example, the conclusion reached is that the best detection probabilities can be achieved if the aircraft receives an update at a time that is less than half the assumed dwell time of the target (where the dwell time must include the move time through a grid, set up time, tear down time, and actual sitting time in one spot). Actual values from this example data may not be accurate, but significant changes in the detection probabilities indicate the value of a possible rule of thumb to carry over to future planning.

Conclusion

From the design of experiments, inferences were made concerning the significance of the selected factors. All main effects were found to be significant at all update times. Search time (B) and the conditional detection probability (D) were thought to affect the overall probability of detection slightly more because of the magnitude of the F test values. Interactions involving two factors seem to lend credence to this inference. When the time unit (C) was combined with B or D, the interaction effect was also significant for all update times. With these inferences in mind, simulation runs were made to develop the desired plot.

Aircraft missions were simulated at different update times to estimate the probability of detection at each

selected time. From the estimate, a plot was developed from which further inferences could be made concerning the "best" time to send an intelligence update to the attacking aircrew. A general conclusion drawn was that the update time should be planned for a time less than one half the total time an SRT spends in one grid. While this is a general result from one set of sample data, further testing could prove this inference to be a valuable rule of thumb.

VII. Recommendations for Further Study

Introduction

Computer simulations are only as good as the assumptions they are built upon and the information put into the model. Building a model to simulate SRT missions has so much uncertainty surrounding the target movement and aircraft search, that the assumptions and input data are critical in determining the value of the results. More specifically, two areas require more research to improve the model's accuracy.

Aircraft Search

To form a realistic search pattern, the grids searched by the aircraft must all be connected. In this model, the search pattern that was developed borrowed some ideas from articles written about search theory. However, the frame of reference in the literature did not consider feasible aircraft flight paths. As stated in Chapter 1, most research addressed the problem of maximizing the probability of detection for a given amount of search effort or time. Searching in this manner may result in the highest possible detection probability (or at least an upper bound on the probability) but does not ensure a feasibe search path.

More research is required to ensure the grids generated for the aircraft to search form a feasible search "path". Two approaches came to mind while studying the problem but

time did not allow further implementation. One approach could involve restrictions placed on the one-step transition matrix. If the transition probabilities were input such that the highest probabilities centered on a certain "path" of grids (such as following a road), the resulting unconditional probabilities would reflect an appropriate path (Fig. 7.1). However, one must be careful in this situation so as not to restrict the search too much so that it is unrealistic.

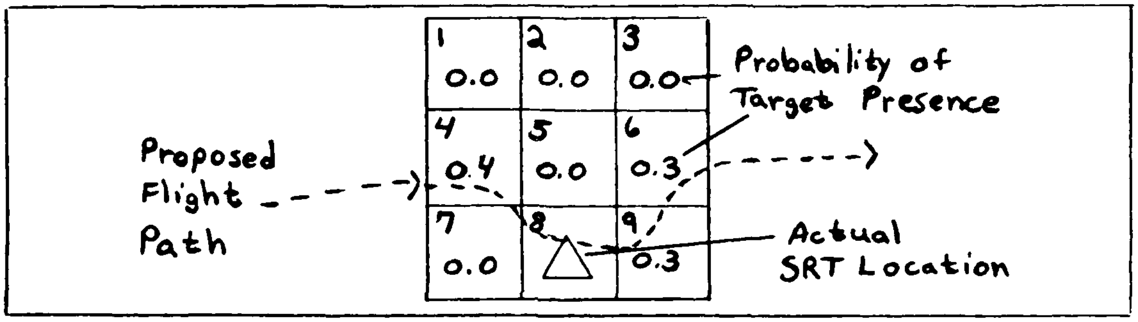


Fig. 7.1. Sample Search Area Where the Probabilities Form a Path

A second approach takes the current search pattern one step farther. After computing the search pattern that gives the upper bound on the probability, a check should be done on the grids to be searched to ensure a path is formed. If not, new grids can be selected to make the pattern a path by continuing down the sorted unconditional probability list. In this way, the new grids selected still have the highest probability of containing the target but with the added constraint of having to form a path with the other selected grids. A check such as this could be incorporated very easily into the present model as a FORTRAN subroutine.

While the actual values for the probability of detection estimates may change, the shape of the curve generated from the estimates versus the update times would not degrade much and would more realistically reflect a real aircraft mission profile.

Target Time in Current Location

Another area that could improve the model deals with how long the target has been in the current location when an update is received by the aircrew. An assumption made in this model is that when the target is spotted by intelligence or by whatever means, the SRT has been there half of the total time normally spent in one location. By dividing the time in half, the error from not knowing the exact time should be reduced. For targets with short dwell times the error will be small. However, as dwell times get larger, errors also increase. Since another assumption for the model is that only short dwell time targets are being considered, more flexibility can be built into the model by developing a routine to better estimate how long the target has been in the current location when the update is observed.

As an example, 79.8 minutes was half the normal time spent in one grid for the SRT's in the previous example. Actual time already spent in the reported grid at the update time averaged about 62 minutes as calculated from the sample output. In fact, only one run had an average time greater than 79.8. Therefore, the target, on the average, had not

been in the reported location as long as the aircrew assumed. Because of this, the aircrew predicted a move by the target before the target actually moved.

On the average, the searches were taking place in grids too far away from the reported position given at the update time. A routine that could better estimate how long a target has been in its current location could improve the accuracy of the model. However, more intelligence updates may be required to compute this estimate and it may prove to be too much effort for the benefit gained. On the other hand, the extra research might turn up an estimating procedure that could improve the accuracy of the model.

Conclusion

Strategic relocatable targets are very uncertain creatures. Much uncertainty surrounds their pattern of movement and attempts to find them. HQ Strategic Air Command and Pentagon planners are continually working to decrease this uncertainty and to plan strikes against SRT's with a high probability of success. However, much more work is still needed.

From this model some of the uncertainty about the target movement has been put to rest. So many problems still exist because every target in every section of enemy territory poses a unique threat with a unique set of information required to find and destroy each SRT. To build a general model to cover all contingencies based on the appropriate

input information may not be possible. However, this model is an attempt to help clear away some of the uncertainty in attacking strategic relocatable targets with the manned bomber.

Appendix A

FORTRAN Program

FORTRAN Program

```
      PROGRAM MAIN
*************************************************************
*                                                           *
* THIS PROGRAM WORKS IN CONJUNCTION WITH THE SLAM PROGRAM   *
* "RELOC.TARGET" TO SIMULATE STRATEGIC BOMBERS ATTACKING    *
* STRATEGIC RELOCATABLE TARGET (SRT'S).  IT IS USED TO DO   *
* THE OPERATIONS THAT SLAM CANNOT DO.  FOR THIS TYPE OF     *
* PROGRAM, THE PRIMARY OPERATIONS ARE MATRIX OPERATIONS     *
* AND SORTING. ALSO, SOME SPECIAL OUTPUT INFORMATION IS     *
* EXTRACTED AND PRINTED TO AN EXTERNAL FILE TO AID IN       *
* FOLLOW ON ANALYSIS.  ALL TIMES ARE IN MINUTES AND RATES   *
* ARE PER MINUTE.                                           *
*                                                           *
*************************************************************
*DECLARATIONS
      DIMENSION NSET(10000)
      CHARACTER*7 TYPE
      REAL SPEED,AVGDIS,TGTDET
      INTEGER DWELL,SETUP,TERDWN,SEARCH,VELCTY
      INTEGER INTTME,MPTIME,CRWRST,RDUNIT,WTUNIT,MAXBOX
      INTEGER RUNCTR,UPINCR
*COMMON STATEMENTS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
                                                 MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
                                                 TNOW,XX(100)
*
      COMMON/INPTS/TYPE,SPEED,DWELL,SETUP,TERDWN,SEARCH,
                                                       VELCTY
     1,AVGDIS,INTTME,MPTIME,CRWRST,TGTDET,SERRAD,LSTGRD,
                                                RUNCTR,UPINCR
*
      COMMON/ARAYS/ONESTP(169,169),STATUS(0:169),ACFTDT(169)
     1,SRTPRB(169,2),DETECT(169),ALLSTP(169,169)
     1,POSTIN(169),TMPMAT(169,169),TMPLOC(169)
     1,TMPSRT(169),TPSTAT(0:169)
*
      COMMON/RDWRT/RDUNIT,WTUNIT
*
      COMMON/ARYSZE/MAXBOX
*
      COMMON QSET(10000)
      EQUIVALENCE(NSET(1),QSET(1))
*OPEN INPUT AND OUTPUT FILES
      OPEN(UNIT=20,FILE='RELOC.SEVENV',STATUS='OLD')
      OPEN(UNIT=21,FILE='RELOC.RESLTV',STATUS='NEW')
*INITIALIZE SLAM VARIABLES
      NNSET=10000
```

```
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
*SET INPUT AND OUTPUT FILE UNIT NUMBERS
      RDUNIT=20
      WTUNIT=21
*SET SIZE OF SEARCH AREA BOX FOR THIS RUN
      MAXBOX=49
*READ IN DATA
      REWIND(UNIT=RDUNIT)
*ONESTP(I,J) IS THE ONE STEP TRANSITION MATRIX
      DO 10, I=1,MAXBOX
          READ(RDUNIT,*)(ONESTP(I,J),J=1,MAXBOX)
10      CONTINUE
*STATUS(I) IS THE VECTOR CONTAINING THE STATUS OF EACH
*GRID (0,1,OR 2)
      READ(RDUNIT,*)(TPSTAT(I),I=0,MAXBOX)
*ACFTDT(I) IS THE VECTOR OF AIRCRAFT SENSOR DETECTION
*FACTORS PER GRID
      READ(RDUNIT,*)(ACFTDT(I),I=1,MAXBOX)
*SET TYPE OF TARGET
      TYPE='MOVABLE'
*SET SPEED OF TARGET
      SPEED=0.25
*SET DWELL TIME OF TARGET (0 FOR MOBILE TARGETS)
      DWELL=60
*SET TIME REQUIRED FOR SETTING UP IN A NEW LOCATION
*AFTER A MOVE
      SETUP=15
*SET TIME REQUIRED TO DISMANTLE EQUIPMENT FOR A NEW MOVE
      TERDWN=15
*SET SEARCH TIME AIRCRAFT IS ALLOWED
      SEARCH=21
*SET AIRSPEED OF AIRCRAFT
      VELCTY=6
*SET AVERAGE DISTANCE TARGET MOVES EACH TIME IT RELOCATES
      AVGDIS=17.4
*SET INTELLIGENCE CYCLE TIME
      INTTME=120
*SET TIME ALLOWED FOR MISSION PLANNING
      MPTIME=60
*SET TIME REQUIRED FOR CREW REST
      CRWRST=480
*SET THE TARGET DETECTION FACTOR
      TGTDET=1.0
*INITIALIZE THE RUN COUNTER
      RUNCTR=10
*INITIALIZE THE INCREMENT OF TIME FOR CHANGING THE
*UPDATE TIME
      UPINCR=60
*RUN THE SLAM PROGRAM
      CALL SLAM
```

```
      STOP
      END
************************************************************
************************************************************
      SUBROUTINE INTLC
************************************************************
*SUBROUTINE INTLC IS CALLED AUTOMATICALLY BEFORE EACH RUN TO
*INITIALIZE APPROPRIATE VARIABLES TO SPECIFIED VALUES
************************************************************
*DECLARATIONS
      CHARACTER*7 TYPE
      REAL SERRAD,TGTDET,SPEED,AVGDIS
      INTEGER INTTME,MPTIME,CRWRST,DWELL
      INTEGER SETUP,TERDWN,VELCTY,SEARCH
      INTEGER MAXBOX,RDUNIT,WTUNIT,LSTGRD
      INTEGER RUNCTR,UPINCR
*COMMON STATEMENTS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
                                                   MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
                                                  TNOW,XX(100)
*
      COMMON/INPTS/TYPE,SPEED,DWELL,SETUP,TERDWN,SEARCH,
                                                       VELCTY
     1,AVGDIS,INTTME,MPTIME,CRWRST,TGTDET,SERRAD,LSTGRD,
                                                 RUNCTR,UPINCR
*
      COMMON/ARAYS/ONESTP(169,169),STATUS(0:169),ACFTDT(169)
     1,SRTPRB(169,2),DETECT(169),ALLSTP(169,169)
     1,POSTIN(169),TMPMAT(169,169),TMPLOC(169)
     1,TMPSRT(169),TPSTAT(0:169)
*
      COMMON/RDWRT/RDUNIT,WTUNIT
*
      COMMON/ARYSZE/MAXBOX
*SET THE SEARCH RADIUS OF THE AIRCRAFT
      SERRAD=8.7
*ESTABLISH MINIMUM FUEL FOR THE AIRCRAFT TO STOP SEARCH
      XX(7)=50.0
*SET FLIGHT TIME FROM TAKEOFF TO BEGIN SEARCH
      XX(3)=360.0
*SET FUEL LOAD FOR THE AIRCRAFT (IN 1000 LBS)
      XX(6)=400.0
*SET MAXIMUM NUMBER OF AIRCRAFT TO FLY PER RUN
      XX(14)=100.0
*SET TIME BETWEEN FUEL DECREMENTS
      XX(36)=30.0
*SET AMOUNT OF FUEL TO DECREASE EACH DECREMENT (IN 1000 LBS)
      XX(37)=0.0
*COMPUTE SYSTEM CYCLE TIME
      XX(31)=INTTME+MPTIME+CRWRST+XX(3)
*COMPUTE GRID SIZE
      XX(39)=SERRAD*2.0
```

```
*COMPUTE TIME IT TAKES AIRCRAFT TO SEARCH ONE GRID
      XX(5)=XX(39)/VELCTY
*SAVE VALUE OF FUEL LOAD
      XX(40)=XX(6)
*COMPUTE NUMBER OF GRIDS AIRCRAFT CAN SEARCH IN
*ALLOTTED TIME
      II=SEARCH/XX(5)
      XX(9)=II
*COMPUTE THE CONDITIONAL DETECTION PROBABILITY (PROBABILITY
*AIRCRAFT SENSES THE TARGET GIVEN THEY ARE BOTH IN THE SAME
*GRID)
      DO 10, I=1,MAXBOX
          DETECT(I)=TGTDET*ACFTDT(I)
10      CONTINUE
*COMPUTE GROUND TIME OF AIRCRAFT (TIME BEFORE TAKEOFF)
      XX(1)=XX(31)-XX(3)
*COMPUTE NUMBER OF GRIDS ON EACH SIDE OF SEARCH AREA BOX
      II=MAXBOX**0.5
      XX(25)=II
*SET TIME OF ARRIVAL IN FIRST GRID TO ZERO
      XX(49)=0.0
*COMPUTE TOTAL DWELL TIME (TOTAL TIME IN ONE GRID) FOR
*THE TARGET
      XX(21)=DWELL+SETUP+TERDWN
*INCREMENT RUN COUNTER
      RUNCTR=RUNCTR+1
      XX(47)=RUNCTR
*COMPUTE THE INTELLIGENCE UPDATE TIME FOR NEXT RUN
      XX(2)=RUNCTR*UPINCR
*FOR MOVABLE TARGETS
      IF(TYPE.EQ.'MOVABLE') THEN
*         COMPUTE TIME TO MAKE ONE MOVE TO A NEW LOCATION
          XX(38)=AVGDIS/SPEED
*         COMPUTE TIME TO MAKE ONE HALF MOVE TO A
*         NEW LOCATION
          XX(20)=XX(38)/2.0
*         COMPUTE TIME UNIT OF STOCHASTIC PROCESS
          XX(41)=XX(21)+XX(38)
        ENDIF
*FOR MOBILE TARGETS (CONSTANTLY IN MOTION)
      IF(TYPE.EQ.'MOBILE') THEN
*         COMPUTE TIME TO MAKE ONE MOVE TO A NEW LOCATION
          XX(38)=XX(39)/SPEED
*         COMPUTE TIME TO MAKE ONE HALF MOVE TO A
*         NEW LOCATION
          XX(20)=XX(38)/2.0
*         COMPUTE TIME UNIT OF STOCHASTIC PROCESS
          XX(41)=XX(38)
        ENDIF
*SAVE INITIAL STATUS OF ALL GRIDS
      DO 20, I=0,MAXBOX
          STATUS(I)=TPSTAT(I)
20      CONTINUE
```

```
      RETURN
      END
**************************************************************
**************************************************************
      SUBROUTINE EVENT(I)
**************************************************************
*SUBROUTINE EVENT IS CALLED BY EVENT NODES IN THE SLAM
*PROGRAM TO DO MATRIX OPERATIONS AND OUTPUT ROUTINES THAT
*SLAM CANNOT DO
**************************************************************
*DECLARATIONS
      DIMENSION GDSRCH(169,2)
      REAL TEMP,TIME,PRETK
      INTEGER NOMOVE,SRTCTR,RUNCTR,UPINCR,GRIDUP
      INTEGER ACPCRT,RDUNIT,WTUNIT,MAXBOX,LSTGRD
*COMMON STATEMENTS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
                                                       MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
                                                       TNOW,XX(100)
*
      COMMON/INPTS/TYPE,SPEED,DWELL,SETUP,TERDWN,SEARCH,
                                                            VELCTY
     1,AVGDIS,INTTME,MPTIME,CRWRST,TGTDET,SERRAD,LSTGRD,
                                                      RUNCTR,UPINCR
*
      COMMON/ARAYS/ONESTP(169,169),STATUS(0:169),ACFTDT(169)
     1,SRTPRB(169,2),DETECT(169),ALLSTP(169,169)
     1,POSTIN(169),TMPMAT(169,169),TMPLOC(169)
     1,TMPSRT(169),TPSTAT(0:169)
*
      COMMON/RDWRT/RDUNIT,WTUNIT
*
      COMMON/ARYSZE/MAXBOX
*BRANCH TO THE CORRECT EVENT
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13),I
**************************************************************
*EVENT 1 COMPUTES THE TARGET LOCATION DISTRIBUTION PREDICTED
*FOR THE AIRCRAFT ARRIVAL TIME IF THE UPDATE IS PRIOR TO
*AIRCRAFT TAKEOFF TIME.  THE DISTRIBUTION IS SORTED FROM
*HIGH TO LOW PROBABILITIES SO THE AIRCRAFT SEARCHES THE
*HIGHEST PROBABILITY AREAS FIRST
**************************************************************
*     COMPUTE THE TIME IT TAKES THE TARGET TO MOVE OUT OF
*     THE FIRST GRID
1     TEMP=(XX(21)/2.0)+XX(20)
      IF(TEMP.LE.XX(2)) THEN
*         TGT MOVES OUT OF FIRST GRID BEFORE THE AIRCRAFT
*         ARRIVES
          II=(XX(2)-TEMP)/XX(41)
*         COMPUTE NUMBER OF MOVES THE TGT WILL MAKE BEFORE
*         ACFT ARRIVES
          XX(42)=II
```

```
          CALL NXTMVE
          CALL NSTEP
          CALL NEWPOS
          CALL LOCATN
          CALL SORT
        ELSE
*         ACFT ARRIVES BEFORE TGT COMPLETES FIRST MOVE
          NOMOVE=1
          CALL NEWPOS
          DO 90, I=1,MAXBOX
              TMPLOC(I)=POSTIN(I)
90          CONTINUE
          CALL SORT
*         SET THE TIME OF THE TGT'S NEXT MOVE PREDICTED
*         BY THE ACFT
          XX(22)=(XX(38)/2.0)+TNOW
        ENDIF
*SET VALUES FOR OUTPUT STATEMENTS
      I=XX(11)+1
      PRETK=XX(2)-XX(3)
      TIME=TNOW-XX(49)
      GRIDUP=XX(15)
      WRITE(WTUNIT,100)I,PRETK,GRIDUP,TIME
100   FORMAT(/' ','FOR MISSION NO ',I3,' AN UPDATE WAS
                                          RECEIVED ',F9.3.'
     1 MINUTES BEFORE TAKEOFF'/' ','THE TARGET WAS DETECTED
                                                 IN GRID NO '
     1,I3,' AND HAD BEEN THERE ',F9.3,' MINUTES'/)
      RETURN
*************************************************************
*EVENT 2 COMPUTES THE TARGET LOCATION DISTRIBUTION PREDICTED
*FOR THE AIRCRAFT ARRIVAL TIME IF THE UPDATE IS AFTER THE
*ACFT TAKEOFF TIME.  THE DISTRIBUTION IS SORTED FROM HIGH TO
*LOW PROBABILITIES SO THE ACFT SEARCHES THE HIGHEST
*PROBABILITY AREAS FIRST
*************************************************************
*COMPUTE THE TIME IT TAKES THE TGT TO MOVE OUT OF THE FIRST
*GRID
2     TEMP=(XX(21)/2.0)+XX(20)
      IF(TEMP.LE.XX(2)) THEN
*         TGT MOVES OUT OF THE FIRST GRID BEFORE THE
*         AIRCRAFT ARRIVES
          II=(XX(2)-TEMP)/XX(41)
*         COMPUTE NUMBER OF MOVES THE TGT WILL MAKE BEFORE
*         ACFT ARRIVES
          XX(42)=II
          CALL NXTMVE
          CALL NSTEP
          CALL NEWPOS
          CALL LOCATN
          CALL SORT
        ELSE
*         AIRCRAFT ARRIVES BEFORE THE TGT MOVES OUT OF
```

```
*          FIRST GRID
           NOMOVE=1
           CALL NEWPOS
           DO 95, I=1,MAXBOX
               TMPLOC(I)=POSTIN(I)
95           CONTINUE
           CALL SORT
*          COMPUTE TIME OF NEXT MOVE PREDICTED BY THE
*          AIRCRAFT
           XX(22)=(XX(38)/2.0)+TNOW
         ENDIF
*SET VALUES FOR THE OUTPUT STATEMENT
       I=XX(11)+1
       TIME=TNOW-XX(49)
       GRIDUP=XX(15)
       WRITE(WTUNIT,110)I,GRIDUP,TIME
110    FORMAT(/' ','FOR MISSION NO ',I3,' AT THE UPDATE
                                                   TIME THE TARGET W
      1AS IN'/' ','GRID NO ',I3,' AND HAD BEEN THERE FOR ',
                                                      F9.3,' MINUTES
      1'/)
       RETURN
************************************************************
*EVENT 3 RETURNS TO THE SLAM PROGRAM WITH THE NEXT GRID FOR
*THE AIRCRAFT TO SEARCH AND ALSO RETURNS THE PROBABILITY OF
*TARGET DETECTION GIVEN THE TARGET IS IN THAT GRID
************************************************************
*UPDATE THE SORTED VECTOR POSITION COUNTER
3      SRTCTR=SRTCTR+1
*UPDATE THE NUMBER OF GRIDS SEARCHED
       XX(10)=XX(10)+1.0
       IF(SRTPRB(SRTCTR,1).GT.0.0) THEN
*          SEARCH THE NEXT GRID ON THE LIST
           XX(13)=DETECT(SRTPRB(SRTCTR,2))
           XX(8)=SRTPRB(SRTCTR,2)
         ELSE
*          NEXT GRID HAS A PROBABILITY=0 OF TARGET PRESENCE
*          GO BACK TO THE FIRST ONE ON THE LIST
           SRTCTR=1
           XX(13)=DETECT(SRTPRB(SRTCTR,2))
           XX(8)=SRTPRB(SRTCTR,2)
         ENDIF
       TIME=TNOW
       I=XX(10)
*SAVE GRID BEING SEARCHED TO BE PRINTED OUT LATER
       GDSRCH(I,1)=XX(8)
       GDSRCH(I,2)=TIME
       RETURN
************************************************************
*EVENT 4 RECOMPUTES THE UNCONDITIONAL LOCATION DISTRIBUTION
*WHEN THE TARGET IS ASSUMED TO HAVE MOVED DURING THE SEARCH
************************************************************
*UPDATE  THE NEXT PREDICTED MOVE TIME
```

```
4       XX(22)=XX(22)+XX(41)
        IF(NOMOVE.EQ.1) THEN
*           COMPUTE APPROPRIATE N-STEP TRANSITION MATRIX
*           FOR ONE MORE MOVE
            XX(42)=0.0
            CALL NSTEP
            NOMOVE=0
          ELSE
            XX(42)=1.0
            CALL NSTEP
          ENDIF
        CALL LOCATN
        CALL SORT
*        WRITE(WTUNIT,120)
*120     FORMAT(//' ','THE TARGET MOVED DURING THE SEARCH'/
                                                  ' ','THE NEW TAR
*       1GET LOCATION DISTRIBUTION IS: '//' ',12X,'GRID
                                              NUMBER',10X,'PROB O
*       1F TARGET PRESENCE'/)
*        DO 20, I=1,MAXBOX
*            IF (SRTPRB(I,1).GT.0) THEN
*                WRITE(WTUNIT,130)SRTPRB(I,2),SRTPRB(I,1)
*130             FORMAT(12X,F5.1,23X,F5.3)
*              ENDIF
*20        CONTINUE
*RESET NEXT POSITION IN SORTED VECTOR TO SEARCH THE TOP OF
*THE LIST
        SRTCTR=0
        RETURN
*************************************************************
*EVENT 5 RESETS APPROPRIATE VARIABLES TO GET READY FOR
*ANOTHER MISSION
*************************************************************
*RESET POSITION ON SORTED VECTOR TO TOP OF LIST
5       SRTCTR=0
*RESET NUMBER OF GRIDS SEARCHED FOR THE CURRENT MISSION
        XX(10)=0.0
*RESET FUEL LOAD ON THE AIRCRAFT
        XX(6)=XX(40)
*RESET N-STEP TRANSITION MATRIX TO THE ONE-STEP TRANSITION
*MATRIX
        DO 40, I=1,MAXBOX
            DO 30, J=1,MAXBOX
                ALLSTP(I,J)=ONESTP(I,J)
30            CONTINUE
40        CONTINUE
*RESET STATUS OF ALL GRIDS TO THE ORIGINAL VALUES
        DO 50, I=0,MAXBOX
            STATUS(I)=TPSTAT(I)
50        CONTINUE
*RESET FIRST MOVE COUNTER TO INDICATE FIRST MOVE
        XX(19)=0.0
*SET STATUS OF INITIAL GRID TO 3
```

```
      XX(24)=3.0
*RESET TARGET DESTRUCTION MARKER TO "DO NOT DESTROY"
      XX(26)=0.0
*RESET TARGET'S LAST POSITION AS GIRD 0
      LSTGRD=0
*COMPUTE ROW OF CENTER GRID FOR INITIAL POSITION OF TARGET
      II=(XX(25)/2.0)+1.0
      XX(17)=II
*SET INITIAL COLUMN POSITION EQUAL TO THE INITIAL ROW FOR
*TARGET
      XX(18)=XX(17)
*COMPUTE CENTER GRID NUMBER FOR TARGET INITIAL POSITION
      II=(MAXBOX/2)+1.0
      XX(15)=II
*SET INITIAL POSITION VECTOR TO THE INITIAL GRID LOCATION
      DO 60, I=1,MAXBOX
          IF(I.EQ.XX(15)) THEN
              POSTIN(I)=1.0
            ELSE
              POSTIN(I)=0.0
            ENDIF
60      CONTINUE
      II=XX(11)+1
*PRINT MESSAGE FOR MISSION NUMBER THAT IS STARTING
      WRITE(NPRNT,140)
140   FORMAT(' ',72('*')/)
      IF(XX(10).EQ.0) WRITE(NPRNT,150)II
150   FORMAT(' ','AIRCRAFT NUMBER ',I3,' SEARCHING NOW:'/)
      RETURN
************************************************************
*EVENT 6 RETURNS THE STATUS OF THE GRID WHICH THE TARGET IS
*TRYING TO MOVE INTO NEXT
************************************************************
6     II=XX(16)
      XX(24)=STATUS(II)
      RETURN
************************************************************
*EVENT 7 CHANGES THE STATUS OF THE NEW TARGET LOCATION TO 1
*AND THE STATUS OF THE OLD GRID BACK TO 2
************************************************************
7     II=XX(15)
      STATUS(II)=1.0
      STATUS(LSTGRD)=2.0
      LSTGRD=II
      RETURN
************************************************************
*EVENT 8 PRINTS A MESSAGE WITH INFORMATION ABOUT THE NEW RUN
************************************************************
8     II=XX(2)
      WRITE(WTUNIT,160)
160   FORMAT(' ',72('*')/)
*PRINT MESSAGE SHOWING THE NEW UPDATE TIME FOR THE CURRENT
*RUN
```

```
      WRITE(WTUNIT,170)II
170   FORMAT(/' ','UPDATE RECEIVED ',I4,' MINUTES BEFORE
                                                SEARCH BEGINS
     1: '/)
      II=XX(47)
      WRITE(NPRNT,180)
180   FORMAT(' ',72('*')/)
*PRINT MESSAGE SHOWING THE NEW RUN NUMBER
      WRITE(NPRNT,190)II
190   FORMAT(' ','FOR RUN NUMBER ',I3,':'/)
      RETURN
***********************************************************
*EVENT 9 PRINTS OUT MESSAGES TO TRACK THE MOVEMENT OF THE
*TARGET AS WELL AS THE TIME OF THE MOVE
***********************************************************
9     II=XX(24)
      TIME=TNOW
      XX(49)=TNOW
      IF(II.EQ.0) THEN
          I=XX(16)
          WRITE(NPRNT,200)I,TIME
200       FORMAT(' ','THE TARGET TRIED TO MOVE TO GRID ',
                                              I3,' AT TIME ',
     1    F11.3)
        ELSEIF(II.EQ.1) THEN
          I=XX(15)
          WRITE(NPRNT,210)I,TIME
210       FORMAT(' ','THE TARGET STARTED MOVING THROUGH
                                            GRID ',I3,' AT T
     1IME ',F11.3)
        ELSEIF(II.EQ.2) THEN
          I=XX(15)
          WRITE(NPRNT,220)I,TIME
220       FORMAT(' ','THE TARGET ENTERED GRID NUMBER ',I3,
                                               ' AT TIME ',F1
     11.3,' TO SET UP')
        ELSEIF(II.EQ.3) THEN
          I=XX(15)
          WRITE(NPRNT,230)I,TIME
230       FORMAT(' ','THE TARGET STARTED IN GRID NUMBER ',
                                               I3,' AT TIME '
     1,F11.3)
        ENDIF
      RETURN
***********************************************************
*EVENT 10 PRINTS OUT A MESSAGE TO INDICATE WHY THE PREVIOUS
*MISSION ENDED
***********************************************************
10    II=XX(46)
      I=XX(11)+1
      GO TO (501,502,503,504),II
501   WRITE(WTUNIT,240)I
240   FORMAT(/' ','MISSION NO ',I3,' ENDED DUE TO NO SEARCH
```

```
                                                        TIME ALLOWED
     1'/)
      RETURN
502   WRITE(WTUNIT,250)I
250   FORMAT(/' ','MISSION NO ',I3,' ENDED DUE TO ALLOTTED
                                                        SEARCH TIME E
     1XPIRED'/)
      RETURN
503   WRITE(WTUNIT,260)I
260   FORMAT(/' ','MISSION NO ',I3,' ENDED DUE TO AIRCRAFT
                                                        BELOW MINIMUM
     1 FUEL'/)
      RETURN
504   WRITE(WTUNIT,270)I
270   FORMAT(/' ','MISSION NO ',I3,' ENDED DUE TO TARGET
                                                         DETECTION'/)
      RETURN
**********************************************************
*EVENT 11 PRINTS OUT THE SORTED UNCONDITIONAL LOCATION
*DISTRIBUTION COMPUTED FROM THE UPDATED INFORMATION THAT THE
*AIRCRAFT WILL USE TO SEARCH FOR THE TARGET INITIALLY
**********************************************************
11    IJK=1
*11    WRITE(WTUNIT,280)
*280   FORMAT(/' ','INITIALLY, THE TARGET LOCATION
                                            DISTRIBUTION ASSUMED B
*     1Y'/' ','THE AIRCRAFT IS (FROM HIGH TO LOW
                                          PROBABILITIES):'///' ',10
*     1X,'GRID NUMBER',10X,'PROB OF TARGET PRESENCE')
*      DO 70, I=1,MAXBOX
*          IF (SRTPRB(I,1).GT.0) THEN
*              WRITE(WTUNIT,290)SRTPRB(I,2),SRTPRB(I,1)
*290           FORMAT(14X,F5.1,23X,F5.3)
*            ENDIF
*70      CONTINUE
      RETURN
**********************************************************
*EVENT 12 PRINTS OUT THE LIST OF GRIDS SEARCHED BY THE
*AIRCRAFT ON HIS MISSION IN THE ORDER THEY WERE SEARCHED AND
*ALSO PRINTS OUT THE TIME THE SEARCH IN EACH GRID STARTED
**********************************************************
12    WRITE(WTUNIT,300)
300   FORMAT(' ','THE AIRCRAFT SEARCHED THE FOLLOWING GRIDS
                                                         IN THE LISTE
     1D ORDER: '//' ','ACFT NO',10X,'GRID SEARCHED',11X,'
                                                      TIME SEARCH BEG
     1AN')
      II=GDSRCH(1,1)
      I=XX(11)
      WRITE(WTUNIT,310)I,II,GDSRCH(1,2)
310   FORMAT(' ',2X,I3,17X,I3,20X,F11.3)
      K=XX(10)
      DO 80, J=2,K
```

```
          II=GDSRCH(J,1)
          WRITE(WTUNIT,320)II,GDSRCH(J,2)
320       FORMAT(' ',22X,I3,20X,F11.3)
80      CONTINUE
      WRITE(WTUNIT,330)
330   FORMAT(' ',72('*')/)
      RETURN
**************************************************************
*EVENT 13 PRINTS A MESSAGE INDICATING THE AIRCRAFT FOUND THE
*CORRECT GRID BUT THE SENSORS DID NOT SEE THE TARGET
**************************************************************
13    II=XX(15)
      WRITE(WTUNIT,340)II
340   FORMAT(/' ','THE AIRCRAFT SEARCHED THE GRID THAT
                                                 CONTAINED'/' ','T
     1HE TARGET BUT STILL MISSED'/' ','(IN GRID NUMBER ',
                                                          I3,')'/)
      RETURN
**************************************************************
      END
**************************************************************
**************************************************************
      SUBROUTINE NSTEP
**************************************************************
*SUBROUTINE NSTEP COMPUTES THE APPROPRIATE N-STEP TRANSITION
*MATRIX CORRESPONDING TO THE NUMBER OF MOVES THE TARGET CAN
*MAKE FROM THE TIME OF THE LAST UPDATE UNTIL THE TIME THE
*SEARCH BEGINS
**************************************************************
*DECLARATIONS
      REAL TEMP
      INTEGER NBRMVE,MAXBOX
*COMMON STATEMENTS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
                                                       MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
                                                      TNOW,XX(100)
*
      COMMON/ARAYS/ONESTP(169,169),STATUS(0:169),ACFTDT(169)
     1,SRTPRB(169,2),DETECT(169),ALLSTP(169,169)
     1,POSTIN(169),TMPMAT(169,169),TMPLOC(169)
     1,TMPSRT(169),TPSTAT(0:169)
*
      COMMON/ARYSZE/MAXBOX
*NUMBER OF MOVES THE TARGET MAKES AFTER INITIAL MOVE
      II=XX(42)
      DO 60, NBRMVE=1,II
*         MULTIPLY THE N-STEP TRANSITION MATRIX BY THE
*         ONE-STEP
          DO 30, I=1,MAXBOX
              DO 20, J=1,MAXBOX
                  TEMP=0.0
                  DO 10, K=1,MAXBOX
```

```
                    TEMP=TEMP+(ONESTP(I,K)*ALLSTP(K,J))
10                 CONTINUE
                 TMPMAT(I,J)=TEMP
20             CONTINUE
30         CONTINUE
         DO 50, I=1,MAXBOX
           DO 40, J=1,MAXBOX
             ALLSTP(I,J)=TMPMAT(I,J)
40         CONTINUE
50       CONTINUE
60     CONTINUE
      RETURN
      END
************************************************************
************************************************************
      SUBROUTINE NEWPOS
************************************************************
*SUBROUTINE NEWPOS RESETS THE INITIAL TARGET POSITION VECTOR
*TO THE NEW POSITION ESTABLISHED FROM THE UPDATED
*INTELLIGENCE INFORMATION
************************************************************
*DECLARATIONS
      INTEGER MAXBOX
*COMMON STATEMENTS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
                                                  MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
                                                 TNOW,XX(100)
*
      COMMON/ARAYS/ONESTP(169,169),STATUS(0:169),ACFTDT(169)
     1,SRTPRB(169,2),DETECT(169),ALLSTP(169,169)
     1,POSTIN(169),TMPMAT(169,169),TMPLOC(169)
     1,TMPSRT(169),TPSTAT(0:169)
*
      COMMON/ARYSZE/MAXBOX
*SET THE VECTOR POSITION TO 1 FOR THE CURRENT TGT LOCATION
*AND 0 FOR OTHERS
      DO 10, I=1,MAXBOX
          IF(I.EQ.XX(15)) THEN
             POSTIN(I)=1.0
          ELSE
             POSTIN(I)=0.0
          ENDIF
10     CONTINUE
      RETURN
      END
************************************************************
************************************************************
      SUBROUTINE LOCATN
************************************************************
*SUBROUTINE LOCATN COMPUTES THE NEW UNCONDITIONAL LOCATION
*DISTRIBUTION OF THE TARGET
************************************************************
```

```
*DECLARATIONS
      REAL TEMP
      INTEGER MAXBOX
*COMMON STATEMENTS
      COMMON/ARAYS/ONESTP(169,169),STATUS(0:169),ACFTDT(169)
     1,SRTPRB(169,2),DETECT(169),ALLSTP(169,169)
     1,POSTIN(169),TMPMAT(169,169),TMPLOC(169)
     1,TMPSRT(169),TPSTAT(0:169)
*
      COMMON/ARYSZE/MAXBOX
*MULTIPLY THE UPDATED POSITION VECTOR BY THE APPROPRIATE
*N-STEP TRANSITION MATRIX
      DO 20, I=1,MAXBOX
            TEMP=0.0
            DO 10 J=1,MAXBOX
                  TEMP=TEMP+(POSTIN(J)*ALLSTP(J,I))
10             CONTINUE
            TMPLOC(I)=TEMP
20       CONTINUE
      RETURN
      END
*************************************************************
*************************************************************
      SUBROUTINE SORT
*************************************************************
*SUBROUTINE SORT SORTS THE UNCONDITIONAL LOCATION
*DISTRIBUTION FROM HIGH TO LOW PROBABILITIES OF TARGET
*PRESENCE IN EACH GRID
*************************************************************
*DECLARATIONS
      INTEGER MAXBOX,RDUNIT,WTUNIT
*COMMON STATEMENTS
      COMMON/ARAYS/ONESTP(169,169),STATUS(0:169),ACFTDT(169)
     1,SRTPRB(169,2),DETECT(169),ALLSTP(169,169)
     1,POSTIN(169),TMPMAT(169,169),TMPLOC(169)
     1,TMPSRT(169),TPSTAT(0:169)
*
      COMMON/RDWRT/RDUNIT,WTUNIT
*
      COMMON/ARYSZE/MAXBOX
*
      DO 10, I=1,MAXBOX
            TMPSRT(I)=TMPLOC(I)
10       CONTINUE
      DO 30, I=1,MAXBOX
*           INITIALLY PUT THE FIRST GRID INFORMATION AT THE
*           TOP OF THE LIST
            SRTPRB(I,1)=TMPSRT(1)
            SRTPRB(I,2)=1.0
            DO 20, J=2,MAXBOX
*                 IF THE PROBABILITY OF THE TARGET BEING IN THE
*                 NEXT GRID ON THE LIST IS GREATER THAN THE
*                 PROBABILITY ALREADY ON THE LIST, SWITCH THEM
```

```
            IF(SRTPRB(I,1).LT.TMPSRT(J)) THEN
               SRTPRB(I,1)=TMPSRT(J)
               SRTPRB(I,2)=J
            ENDIF
20        CONTINUE
*          MARK THE SPOTS ALREADY PUT ON THE SORTED LIST
           TMPSRT(SRTPRB(I,2))=-1.0
30      CONTINUE
      RETURN
      END
************************************************************
************************************************************
      SUBROUTINE NXTMVE
************************************************************
*SUBROUTINE NXTMVE COMPUTES THE TIME THE AIRCRAFT ASSUMES
*THE TARGET WILL MOVE AGAIN
************************************************************
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
                                                      MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
                                                      TNOW,XX(100)
*
      FSTMVE=XX(20)+(XX(21)/2.0)
      II=XX(42)
      XX(22)=FSTMVE+((XX(21)+XX(38))*(II+1))+TNOW
      RETURN
      END
************************************************************
************************************************************
      SUBROUTINE OTPUT
************************************************************
*SUBROUTINE OTPUT PRINTS OUT ANY INFORMATION DESIRED OTHER
*THAN THE STANDARD SLAM OUTPUT
************************************************************
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
                                                      MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
                                                      TNOW,XX(100)
*
      RETURN
      END
************************************************************
************************************************************
```

Appendix B

SLAM Program

SLAM Program

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GEN,OLYNICK,RELOCATABLE TARGETS, 12/13/85,3,N,N;
LIMITS,0,0,5;
;*************************************************************
;*************************************************************
;*  THIS PROGRAM COMPUTES THE PROBABILITY OF DETECTING        *
;*  A STRATEGIC RELOCATABLE TARGET (SRT) BY A STRATEGIC       *
;*  BOMBER.  INPUT VARIABLES AND THEIR DESCRIPTIONS ARE       *
;*  IN THE FORTRAN "PROGRAM MAIN".  AFTER SOME VARIABLES      *
;*  ARE INPUT AND OTHER VARIABLE VALUES ARE INITIALIZED       *
;*  WITH THE INPUT VALUES, THE COMBINATION NETWORK-           *
;*  DISCRETE SIMULATION STARTS. A TARGET MOVES ACCORDING      *
;*  TO THE DEFINED STOCHASTIC PROCESS WHILE SIMULTANEOUSLY *
;*  AN AIRCRAFT MISSION IS SIMULATED FROM THE TIME AN SRT  *
;*  LEAVES ITS MAIN OPERATING BASE (MOB) UNTIL THE AIRCRAFT*
;*  EITHER FINDS THE TARGET OR REACHES HIS TIME OR FUEL       *
;*  RESTRICTION.  DURING EACH MISSION, THE AIRCRAFT WILL      *
;*  RECEIVE AN INTELLIGENCE UPDATE ON THE TARGET'S LOCATION*
;*  A SERIES OF MISSIONS ARE FLOWN FOR EACH OF A SET OF       *
;*  UPDATE TIMES WITH A SUBSEQUENT COMPARISON OF THE PROB- *
;*  ABILITY OF DETECTING THE TARGET GIVEN A PARTICULAR        *
;*  UPDATE TIME.  FROM THIS COMPARISON, BASED ON OTHER        *
;*  INPUT VALUES, A CHOICE CAN BE MADE FOR AN INTELLIGENCE *
;*  UPDATE TIME THAT CAN ENSURE A HIGH PROBABILITY OF         *
;*  DETECTION BY THE ATTACKING AIRCREW.                       *
;*************************************************************
;*************************************************************
;
;*****  THE NETWORK MODEL     ******************************
;
NETWORK;
;
;*****      DEFINITION OF VARIABLES      ********************
;
;   XX(1)     TIME FROM WHEN TARGET LEAVES MOB (TIME 0) UNTIL
;             AIRCRAFT T/O
;   XX(2)     TIME REMAINING UNTIL BEGIN SEARCH AFTER UPDATE
;             RECEIVED
;   XX(3)     TIME FROM TAKEOFF(T/O) UNTIL BEGIN SEARCH
;   XX(4)     TIME FROM INTELL INFO REC(TIME 0) UNTIL RECEIVE
;             UPDATE
;   XX(5)     TIME IT TAKES AIRCRAFT TO SEARCH ONE GRID
;   XX(6)     FUEL LOAD ON THE AIRCRAFT AT T/O TIME
;   XX(7)     MINIMUM FUEL WHEN AIRCRAFT MUST STOP SEARCH
;   XX(8)     GRID NUMBER AIRCRAFT IS SEARCHING
;   XX(9)     NUMBER OF GRIDS THE AIRCRAFT CAN SEARCH IN
;             ALLOTTED TIME
;  XX(10)     THE NUMBER OF GRIDS SEARCHED SO FAR BY THE
;             CURRENT AIRCRAFT
;  XX(11)     NUMBER OF AIRCRAFT FLOWN WITH CURRENT UPDATE
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;              TIME
; XX(12)       NUMBER OF AIRCRAFT THAT MISS THE TARGET FOR ONE
;              UPDATE TIME
; XX(13)       PROBABILITY OF AIRCRAFT DETECTING THE TARGET IN
;              THE GRID BEING SEARCHED GIVEN THE TARGET IS
;              THERE
; XX(14)       MAXIMUM NUMBER OF AIRCRAFT TO FLY PER UPDATE
;              TIME
; XX(15)       GRID NUMBER OF TARGET LOCATION
; XX(16)       GRID NUMBER TO MOVE THE TARGET TO NEXT WHILE
;              THE STATUS OF THE GRID IS BEING CHECKED FOR AN
;              ACCEPTABLE MOVE
; XX(17)       ROW NUMBER OF THE TARGET LOCATION
; XX(18)       COLUMN NUMBER OF THE TARGET LOCATION
; XX(19)       MARKER:  0-FIRST MOVE OF TARGET   1-SECOND OR
;              LATER MOVE
; XX(20)       TIME IT TAKES TARGET TO MOVE HALF WAY ACROSS
;              ONE GRID
; XX(21)       TOTAL TIME TARGET STAYS IN ONE LOCATION
; XX(22)       TIME PREDICTED BY AIRCRAFT FOR THE TARGET'S
;              NEXT MOVE
; XX(23)       RANDOM NUMBER FOR DIRECTION OF TARGET'S NEXT
;              MOVE
; XX(24)       STATUS OF GRID CHOSEN FOR NEXT LOCATION
;                     0 - STAY OUT
;                     1 - PASS THROUGH ONLY
;                     2 - RELOCATE
; XX(25)       NUMBER OF GRIDS IN ONE ROW/COLUMN OF REGION
; XX(26)       MARKER:  0-CONTINUE MISSION    1-END MISSION
; XX(27)       RANDOM NUMBER USED IN TARGET IDENTIFICATION
; XX(28)       NUMBER OF AIRCRAFT THAT DETECT THE TARGET PER
;              UPDATE TIME
; XX(29)       PROBABILITY OF DETECTION PER UPDATE TIME
; XX(30)       DIFFERENCE BETWEEN THE SYSTEM CYCLE TIME AND
;              LATEST UPDATE
; XX(31)       SYSTEM CYCLE TIME (TIME FROM INTELLIGENCE
;              INFORMATION COLLECTED UNTIL WEAPON OVER TARGET)
; XX(32)       TIME INCREMENT USED BETWEEN UPDATE TIMES BEING
;              CHECKED
; XX(33)       MARKER:    0-NEXT RUN NOT LAST RUN
;                         1-NEXT RUN IS LAST RUN
; XX(35)       TIME BETWEEN ACTUAL END OF MISSION AND LATEST
;              END POSSIBLE
; XX(36)       TIME BETWEEN DECREASES IN FUEL ON BOARD THE
;              AIRCRAFT
; XX(37)       AMOUNT OF FUEL TO DECREASE THE AIRCRAFT FUEL
;              EACH INCREMENT
; XX(38)       TIME FOR SRT TO MOVE ONE GRID
; XX(39)       GRID SIZE IN MILES
; XX(40)       SAVES INITIAL FUEL LOAD BETWEEN RUNS
; XX(41)       TIME UNIT OF STOCHASTIC PROCESS
; XX(42)       NUMBER OF MOVES SRT MAKES AFTER FIRST MOVE
;              BEFORE AIRCRAFT ARRIVES TO BEGIN SEARCH
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; XX(46)      MARKER FOR REASON FOR MISSION TERMINATION
; XX(47)      KEEPS TRACK OF THE RUN NUMBER
; XX(48)      TIME BEFORE TAKEOFF THAT AN UPDATE MAY BE
;             RECEIVED
; XX(49)      SIMULATION TIME TARGET MOVES INTO A NEW GRID
;
;*****   CREATE AIRCRAFT AND FLY IT TO THE SEARCH AREA    ***
;
      CREATE;                                   CREATE AIRCRAFT
        ACT;
DOAGN ASSIGN,XX(11)=0,
             XX(12)=0,
             XX(28)=0,   1;                     RESET ACFT COUNTERS
                                                FOR NEW RUN
        ACT;
      EVENT,8,1;                                RESET OTHER VAR-
                                                IABLES FOR NEW RUN
        ACT;
ACFT  EVENT,5,2;                                UPDATE VARIABLES
                                                FOR A NEW
;                                               AIRCRAFT MISSION
        ACT,,,MOVE;                             CREATE TARGET
        ACT;                                    CONTINUE WITH
                                                AIRCRAFT
      ASSIGN,XX(4)=XX(31)-XX(2),   1;           COMPUTE TIME UNTIL
                                                INTEL UPDATE
        ACT,,XX(4).GT.XX(1),UPDAT;              UPDATE COMES AFTER
                                                TAKEOFF
        ACT,XX(4);                              UPDATE COMES BEFORE
                                                T/O, DELAY
;                                               UNTIL UPDATE TIME
;****  COMPUTATIONS FOR UPDATE PRIOR TO T/O  ***************
      EVENT,1,1;                                COMPUTE NEW TARGET
                                                LOCATION
;                                               DISTRIBUTION
        ACT;
      EVENT,11,1;                               PRINT TGT LOCATION
                                                DISTRIBUTION
        ACT;
      ASSIGN,XX(48)=XX(2)-XX(3), 2;             COMPUTE T/O TIME
        ACT,XX(48),,FULDN;                      START DECREASING FUEL
        ACT,XX(48);                             DELAY UNTIL T/O
                                                TIME
      GOON,1;
        ACT,XX(3),,SERCH;                       FLY TO SEARCH AREA
;****  COMPUTATIONS FOR UPDATE AFTER T/O  ******************
UPDAT GOON,2;
        ACT,XX(1),,FULDN;                       START FUEL
                                                DECREASING AFTER
                                                T/O
        ACT,XX(4);                              FLY TO UPDATE POINT
      EVENT,2,1;                                COMPUTE TGT LOCA-
                                                TION DISTRIBUTION
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        ACT;
      EVENT,11,1;                                 PRINT TGT LOCATION
                                                  DISTRIBUTION
        ACT,XX(2),,SERCH;                         FLY TO SEARCH AREA
;****      BEGIN SEARCH FOR TARGET     **********************
SERCH EVENT,3,1;                                  PUT ACFT IN FIRST
                                                  GRID TO SEARCH
        ACT,,XX(9).EQ.0,E1MSG;                    STOP, NO SEARCH
                                                  TIME ALLOWED
        ACT,XX(5),XX(15).EQ.XX(8),CKFND;           ACFT AND TGT IN
                                                  SAME GRID, CHECK
;                                                 FOR DETECTION
        ACT,XX(5);
      GOON,1;
        ACT,,XX(10).GE.XX(9),E2MSG;               STOP, SEARCHED ALL
                                                  GRIDS ALLOWED
        ACT,,XX(6).LE.XX(7),E3MSG;                STOP, ACFT AT
                                                  MINIMUM FUEL
        ACT,,TNOW.GE.XX(22),MVAGN;                TGT MOVED DURING
                                                  SEARCH
;                                                 RECOMPUTE LOCATION
                                                  DISTRIBUTION
        ACT,,,SERCH;                              NO DETECTION,
                                                  SEARCH NEXT GRID
;*****  ACFT IN CORRECT GRID, CHECK IF DETECT TGT  *********
CKFND ASSIGN,XX(27)=UNFRM(0.,1.,4),  1;           CHOOSE RANDOM
                                                  NUMBER
        ACT,,XX(27).LE.XX(13),E4MSG;              RANDOM NUMBER LESS
                                                  THAN DETECTION
;                                                 PROBABILITY, ACFT
                                                  FOUND TGT
        ACT;                                      SENSORS DID NOT SEE
                                                  TGT, CONTINUE
      EVENT,13,1;                                 PRINT MESSAGE OF
                                                  DETECT FAILURE
        ACT,,XX(10).GE.XX(9),E2MSG;               STOP, SEARCHED ALL
                                                  GRIDS ALLOWED
        ACT,,XX(6).LE.XX(7),E3MSG;                STOP, ACFT AT
                                                  MINIMUM FUEL
        ACT,,TNOW.GE.XX(22),MVAGN;                TGT MOVED DURING
                                                  SEARCH
;                                                 RECOMPUTE LOCATION
                                                  DISTRIBUTION
        ACT,,,SERCH;                              NO DETECTION,
                                                  SEARCH NEXT GRID
;****  RECOMPUTE TARGET LOCATION DISTRIBUTION  *************
MVAGN EVENT,4,1;
        ACT,,,SERCH;                              CONTINUE SEARCH
                                                  WITH NEW
;                                                 DISTRIBUTION
;****  START TARGET MOVEMENT  ******************************
MOVE  EVENT,7,1;                                  RESET STATUS OF
                                                  CURRENT TGT
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;                                                  LOCATION TO ONE FOR
                                                   NEXT MOVE
       ACT,,XX(19).EQ.0.,FSMVE;                    TGT'S FIRST MOVE,
                                                   DO NOT DWELL
       ACT;                                        SECOND OR LATER
                                                   MOVE, DWELL
;                                                  BEFORE MOVE AGAIN
     GOON,2;
       ACT,,,DLAGN;                                STAY IN CURRENT
                                                   GRID FOR
       ACT,STOPA(1);                               ASSIGNED DWELL TIME
FSMVE ASSIGN,XX(19)=1.,    1;                      RESET FIRST MOVE
                                                   MARKER
       ACT,,XX(26).EQ.1,WTTGT;                     STOP, TARGET
                                                   DETECTED
       ACT;
;**  CHECK TARGET'S CURRENT POSITION BEFORE CHOOSING NEW ***
;**  DIRECTION; DIRECTIONS ARE ORIENTED AS UP=NORTH,     ***
;**  DOWN=SOUTH, LEFT=WEST, AND RIGHT=EAST; FOR THE SEARCH *
;**  AREA BOX, THE LEFT EDGE=WEST SIDE, THE RIGHT EDGE=  ***
;**  EAST SIDE, THE TOP ROW=NORTH SIDE, AND THE BOTTOM   ***
;**  ROW=SOUTH SIDE                                      ***
TOPRW GOON,1;
       ACT,,XX(24).EQ.0.OR.
            XX(24).EQ.3,TELME;                     STATUS OF CURRENT
                                                   GRID IS 0 OR 3
       ACT,,,NOGO;                                 STATUS OF CURRENT
                                                   GRID IS 1 OR 2
TELME EVENT,9,1;                                   PRINT MESSAGE FOR
                                                   TGT MOVEMENT
       ACT;
NOGO  GOON,1;
       ACT,,XX(17).GT.1,BTMRW;                     TGT NOT IN TOP ROW
       ACT,,XX(18).GT.1,URTCR;                     IN TOP ROW, BUT NOT
                                                   ON LEFT EDGE
       ACT,,,ULTCR;                                TGT IN UPPER LEFT
                                                   CORNER
ULTCR ASSIGN,XX(23)=UNFRM(0.,3.,4),   1;           CHOOSE RANDOM
                                                   NUMBER FOR MOVE
       ACT,,XX(23).LT.1,EMOVE;                     MOVE EAST
       ACT,,XX(23).LT.2,SEMVE;                     MOVE SOUTH EAST
       ACT,,,SMOVE;                                MOVE SOUTH
URTCR GOON,1;
       ACT,,XX(18).LT.XX(25),MIDTP;                IN TOP ROW, NOT
                                                   ON RIGHT EDGE
       ACT;                                        IN UPPER RIGHT
                                                   CORNER
     ASSIGN,XX(23)=UNFRM(0.,3.,4),   1;            CHOOSE RANDOM
                                                   NUMBER FOR MOVE
       ACT,,XX(23).LT.1,WMOVE;                     MOVE WEST
       ACT,,XX(23).LT.2,SWMVE;                     MOVE SOUTH WEST
       ACT,,,SMOVE;                                MOVE SOUTH
MIDTP ASSIGN,XX(23)=UNFRM(0.,5.,4),   1;           IN MIDDLE OF TOP
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                                               ROW
;                                              CHOOSE RANDOM
                                               NUMBER FOR MOVE
        ACT,,XX(23).LT.1,EMOVE;                MOVE EAST
        ACT,,XX(23).LT.2,SEMVE;                MOVE SOUTH EAST
        ACT,,XX(23).LT.3,SMOVE;                MOVE SOUTH
        ACT,,XX(23).LT.4,SWMVE;                MOVE SOUTH WEST
        ACT,,,WMOVE;                           MOVE WEST
BTMRW GOON,1;
        ACT,,XX(17).LT.XX(25),LFEGE;           TGT NOT IN BOTTOM
                                               ROW
        ACT,,XX(18).GT.1,LRTCR;                IN BOTTOM ROW, NOT
                                               ON LEFT EDGE
        ACT,,,LLTCR;                           IN LOWER LEFT
                                               CORNER
LLTCR ASSIGN,XX(23)=UNFRM(0.,3.,4),   1;       CHOOSE RANDOM
                                               NUMBER FOR MOVE
        ACT,,XX(23).LT.1,NMOVE;                MOVE NORTH
        ACT,,XX(23).LT.2,NEMVE;                MOVE NORTH EAST
        ACT,,,EMOVE;                           MOVE EAST
LRTCR GOON,1;
        ACT,,XX(18).LT.XX(25),MDBTM;           IN BOTTOM ROW, NOT
                                               ON RIGHT EDGE
        ACT;                                   IN LOWER RIGHT
                                               CORNER
      ASSIGN,XX(23)=UNFRM(0.,3.,4),   1;       CHOOSE RANDOM
                                               NUMBER FOR MOVE
        ACT,,XX(23).LT.1,NMOVE;                MOVE NORTH
        ACT,,XX(23).LT.2,NWMVE;                MOVE NORTH WEST
        ACT,,,WMOVE;                           MOVE WEST
MDBTM ASSIGN,XX(23)=UNFRM(0.,5.,4),   1;       IN MIDDLE OF BOTTOM
                                               ROW
;                                              CHOOSE RANDOM
                                               NUMBER FOR MOVE
        ACT,,XX(23).LT.1,WMOVE;                MOVE WEST
        ACT,,XX(23).LT.2,NWMVE;                MOVE NORTH WEST
        ACT,,XX(23).LT.3,NMOVE;                MOVE NORTH
        ACT,,XX(23).LT.4,NEMVE;                MOVE NORTH EAST
        ACT,,,EMOVE;                           MOVE EAST
LFEGE GOON,1;
        ACT,,XX(18).GT.1,RTEGE;                TGT NOT ON LEFT
                                               EDGE
        ACT,,,MIDLF;                           TGT IN MIDDLE OF
                                               LEFT EDGE
MIDLF ASSIGN,XX(23)=UNFRM(0.,5.,4),   1;       CHOOSE RANDOM
                                               NUMBER FOR MOVE
        ACT,,XX(23).LT.1,NMOVE;                MOVE NORTH
        ACT,,XX(23).LT.2,NEMVE;                MOVE NORTH EAST
        ACT,,XX(23).LT.3,EMOVE;                MOVE EAST
        ACT,,XX(23).LT.4,SEMVE;                MOVE SOUTH EAST
        ACT,,,SMOVE;                           MOVE SOUTH
RTEGE GOON,1;
        ACT,,XX(18).LT.XX(25),MIDEX;           NOT ON RIGHT EDGE
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          ACT,,,MIDRT;                          TGT IN MIDDLE OF
                                                RIGHT EDGE
MIDRT ASSIGN,XX(23)=UNFRM(0.,5.,4),    1;       CHOOSE RANDOM
                                                NUMBER
          ACT,,XX(23).LT.1,NMOVE;               MOVE NORTH
          ACT,,XX(23).LT.2,NWMVE;               MOVE NORTH WEST
          ACT,,XX(23).LT.3,WMOVE;               MOVE WEST
          ACT,,XX(23).LT.4,SWMVE;               MOVE SOUTH WEST
          ACT,,,SMOVE;                          MOVE SOUTH
MIDBX ASSIGN,XX(23)=UNFRM(0.,8.,4),    1,       TGT IN MIDDLE OF
                                                SEARCH AREA,
;                                               CHOOSE RANDOM
                                                NUMBER
          ACT,,XX(23).LT.1,NWMVE;               MOVE NORTH WEST
          ACT,,XX(23).LT.2,NMOVE;               MOVE NORTH
          ACT,,XX(23).LT.3,NEMVE;               MOVE NORTH EAST
          ACT,,XX(23).LT.4,EMOVE;               MOVE EAST
          ACT,,XX(23).LT.5,SEMVE;               MOVE SOUTH EAST
          ACT,,XX(23).LT.6,SMOVE;               MOVE SOUTH
          ACT,,XX(23).LT.7,SWMVE;               MOVE SOUTH WEST
          ACT,,,WMOVE;                          MOVE WEST
;****   MOVE TARGET   ****************************************
NWMVE ASSIGN,XX(16)=XX(15)-XX(25)-1,    1;      COMPUTE NEW GRID
                                                NUMBER
          ACT;
        EVENT,6,1;                              GET STATUS OF NEW
                                                GRID
          ACT,,XX(24).EQ.0,TOPRW;               STATUS=0, DO NOT
                                                MOVE
          ACT;                                  MOVE TO NEW GRID
        GOON,2;
          ACT,,,HFMVE;                          MOVE TARGET OUT OF
                                                OLD GRID
          ACT,STOPA(5);                         TO THE EDGE OF
                                                THE NEW GRID
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;               STOP, TARGET
                                                DETECTED
          ACT;
        ASSIGN,XX(15)=XX(16),
               XX(17)=XX(17)-1,
               XX(18)=XX(18)-1,    1;           CHANGE TGT LOCATION
                                                TO NEW GRID
          ACT;
        EVENT,9,1;                              PRINT MESSAGE ABOUT
                                                TGT MOVE
          ACT;
        GOON,2;
          ACT,,,HFMVE;                          MOVE TARGET TO THE
                                                CENTER OF
          ACT,STOPA(5);                         THE NEW GRID
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;               STOP, TARGET
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                                                  DETECTED
        ACT;
      GOON,1;
        ACT,,XX(24).EQ.1,TOPRW;                   STATUS=1, MOVE
                                                  AGAIN BEFORE DWELL
        ACT,,,MOVE;                               STATUS=2, DWELL
                                                  BEFORE MOVE AGAIN
;*************************************************************
NMOVE ASSIGN,XX(16)=XX(15)-XX(25),   1;           COMPUTE NEW GRID
                                                  NUMBER
        ACT;
      EVENT,6,1;                                  GET STATUS OF NEW
                                                  GRID
        ACT,,XX(24).EQ.0,TOPRW;                   STATUS=0, DO NOT
                                                  MOVE
        ACT;
      GOON,2;
        ACT,,,HFMVE;                              MOVE TARGET OUT OF
                                                  OLD GRID
        ACT,STOPA(5);                             TO THE EDGE OF THE
                                                  NEW GRID
      GOON,1;
        ACT,,XX(26).EQ.1,WTTGT;                   STOP, TARGET
                                                  DETECTED
        ACT;
      ASSIGN,XX(15)=XX(16),
             XX(17)=XX(17)-1,   1;                CHANGE TGT LOCATION
                                                  TO NEW GRID
        ACT;
      EVENT,9,1;                                  PRINT MESSAGE ABOUT
                                                  TGT MOVE
        ACT;
      GOON,2;
        ACT,,,HFMVE;                              MOVE TARGET TO THE
                                                  CENTER
        ACT,STOPA(5);                             OF THE NEW GRID
      GOON,1;
        ACT,,XX(26).EQ.1,WTTGT;                   STOP, TARGET
                                                  DETECTED
        ACT;
      GOON,1;
        ACT,,XX(24).EQ.1,TOPRW;                   STATUS=1, MOVE
                                                  AGAIN BEFORE DWELL
        ACT,,,MOVE;                               STATUS=0, DWELL
                                                  BEFORE MOVE AGAIN
;*************************************************************
NEMVE ASSIGN,XX(16)=XX(15)-XX(25)+1,   1;         COMPUTE NEW GRID
                                                  NUMBER
        ACT;
      EVENT,6,1;                                  GET STATUS OF GRID
        ACT,,XX(24).EQ.0,TOPRW;                   STATUS=0, DO NOT
                                                  MOVE
        ACT;
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        GOON,2;
          ACT,,,HFMVE;                          MOVE TARGET OUT OF
                                                OLD GRID
          ACT,STOPA(5);                         TO THE EDGE OF THE
                                                NEW GRID
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;               STOP, TARGET
                                                DETECTED
          ACT;
        ASSIGN,XX(15)=XX(16),
               XX(17)=XX(17)-1,
               XX(18)=XX(18)+1,   1;            CHANGE TGT LOCATION
                                                TO NEW GRID
          ACT;
        EVENT,9,1;                              PRINT MESSAGE ABOUT
                                                TGT MOVE
          ACT;
        GOON,2;
          ACT,,,HFMVE;                          MOVE TARGET TO THE
                                                CENTER
          ACT,STOPA(5);                         OF THE NEW GRID
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;               STOP, TARGET
                                                DETECTED
          ACT;
        GOON,1;
          ACT,,XX(24).EQ.1,TOPRW;               STATUS=1, MOVE
                                                AGAIN BEFORE DWELL
          ACT,,,MOVE;                           STATUS=2, DWELL
                                                BEFORE MOVE AGAIN
;************************************************************
EMOVE   ASSIGN,XX(16)=XX(15)+1,   1;            COMPUTE NEW GRID
                                                NUMBER
          ACT;
        EVENT,6,1;                              GET STATUS OF NEW
                                                GRID
          ACT,,XX(24).EQ.0,TOPRW;               STATUS=0, DO NOT
                                                MOVE
          ACT;
        GOON,2;
          ACT,,,HFMVE;                          MOVE TARGET OUT OF
                                                OLD GRID
          ACT,STOPA(5);                         TO THE EDGE OF THE
                                                NEW GRID
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;               STOP, TARGET
                                                DETECTED
          ACT;
        ASSIGN,XX(15)=XX(16),
               XX(18)=XX(18)+1,   1;            CHANGE TGT LOCATION
                                                TO NEW GRID
          ACT;
        EVENT,9,1;                              PRINT MESSAGE ABOUT
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                                                  TGT MOVE
        ACT;
       GOON,2;
        ACT,,,HFMVE;                              MOVE TARGET TO THE
                                                  CENTER
        ACT,STOPA(5);                             OF THE NEW GRID
       GOON,1;
        ACT,,XX(26).EQ.1,WTTGT;                   STOP, TARGET
                                                  DETECTED
        ACT;
       GOON,1;
        ACT,,XX(24).EQ.1,TOPRW;                   STATUS=1, MOVE
                                                  AGAIN BEFORE DWELL
        ACT,,,MOVE;                               STATUS=2, DWELL
                                                  BEFORE MOVE AGAIN
;*************************************************************
SEMVE ASSIGN,XX(16)=XX(15)+XX(25)+1,    1;  COMPUTE NEW GRID
                                                  NUMBER
        ACT;
       EVENT,6,1;                                 GET STATUS OF NEW
                                                  GRID
        ACT,,XX(24).EQ.0,TOPRW;                   STATUS=0, DO NOT
                                                  MOVE
        ACT;
       GOON,2;
        ACT,,,HFMVE;                              MOVE TARGET OUT OF
                                                  OLD GRID
        ACT,STOPA(5);                             TO THE EDGE OF THE
                                                  NEW GRID
       GOON,1;
        ACT,,XX(26).EQ.1,WTTGT;                   STOP, TARGET
                                                  DETECTED
        ACT;
       ASSIGN,XX(15)=XX(16),
              XX(17)=XX(17)+1,
              XX(18)=XX(18)+1,    1;              CHANGE TGT LOCATION
                                                  TO NEW GRID
        ACT;
       EVENT,9,1;                                 PRINT MESSAGE ABOUT
                                                  TGT MOVE
        ACT;
       GOON,2;
        ACT,,,HFMVE;                              MOVE TARGET TO THE
                                                  CENTER
        ACT,STOPA(5);                             OF THE NEW GRID
       GOON,1;
        ACT,,XX(26).EQ.1,WTTGT;                   STOP, TARGET
                                                  DETECTED
        ACT;
       GOON,1;
        ACT,,XX(24).EQ.1,TOPRW;                   STATUS=1, MOVE
                                                  AGAIN BEFORE DWELL
        ACT,,,MOVE;                               STATUS=2, DWELL
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                                                   BEFORE MOVE AGAIN
;*************************************************************************
SMOVE ASSIGN,XX(16)=XX(15)+XX(25),   1;    COMPUTE NEW GRID
                                           NUMBER
        ACT;
      EVENT,6,1;                           GET STATUS OF NEW
                                           GRID
        ACT,,XX(24).EQ.0,TOPRW;            STATUS=0, DO NOT
                                           MOVE
        ACT;
      GOON,2;
        ACT,,,HFMVE;                       MOVE TARGET OUT OF
                                           OLD GRID
        ACT,STOPA(5);                      TO THE EDGE OF THE
                                           NEW GRID
      GOON,1;
        ACT,,XX(26).EQ.1,WTTGT;            STOP, TARGET
                                           DETECTED
        ACT;
      ASSIGN,XX(15)=XX(16),
             XX(17)=XX(17)+1,   1;         CHANGE TGT LOCATION
                                           TO NEW GRID
        ACT;
      EVENT,9,1;                           PRINT MESSAGE ABOUT
                                           TGT MOVE
        ACT;
      GOON,2;
        ACT,,,HFMVE;                       MOVE TARGET TO THE
                                           CENTER
        ACT,STOPA(5);                      OF THE NEW GRID
      GOON,1;
        ACT,,XX(26).EQ.1,WTTGT;            STOP, TARGET
                                           DETECTED
        ACT;
      GOON,1;
        ACT,,XX(24).EQ.1,TOPRW;            STATUS=1, MOVE
                                           AGAIN BEFORE DWELL
        ACT,,,MOVE;                        STATUS=2, DWELL
                                           BEFORE MOVE AGAIN
;*************************************************************************
SWMVE ASSIGN,XX(16)=XX(15)+XX(25)-1,   1; COMPUTE NEW GRID
                                           NUMBER
        ACT;
      EVENT,6,1;                           GET STATUS OF NEW
                                           GRID
        ACT,,XX(24).EQ.0,TOPRW;            STATUS=0, DO NOT
                                           MOVE
        ACT;
      GOON,2;
        ACT,,,HFMVE;                       MOVE TARGET OUT OF
                                           OLD GRID
        ACT,STOPA(5);                      TO THE EDGE OF THE
                                           NEW GRID
```

```
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;                  STOP, TARGET
                                                   DETECTED
          ACT;
        ASSIGN,XX(15)=XX(16),
               XX(17)=XX(17)+1,
               XX(18)=XX(18)-1,    1;              CHANGE TGT LOCATION
                                                   TO NEW GRID
          ACT;
        EVENT,9,1;                                 PRINT MESSAGE ABOUT
                                                   TGT MOVE
          ACT;
        GOON,2;
          ACT,,,HFMVE;                             MOVE TARGET TO THE
                                                   CENTER
          ACT,STOPA(5);                            OF THE NEW GRID
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;                  STOP, TARGET
                                                   DETECTED
          ACT;
        GOON,1;
          ACT,,XX(24).EQ.1,TOPRW;                  STATUS=1, MOVE
                                                   AGAIN BEFORE DWELL
          ACT,,,MOVE;                              STATUS=2, DWELL
                                                   BEFORE MOVE AGAIN
;*************************************************************
WMOVE ASSIGN,XX(16)=XX(15)-1,    1;                COMPUTE NEW GRID
                                                   NUMBER
          ACT;
        EVENT,6,1;                                 GET STATUS OF NEW
                                                   GRID
          ACT,,XX(24).EQ.0,TOPRW;                  STATUS=0, DO NOT
                                                   MOVE
          ACT;
        GOON,2;
          ACT,,,HFMVE;                             MOVE TARGET OUT OF
                                                   OLD GRID
          ACT,STOPA(5);                            TO THE EDGE OF THE
                                                   NEW GRID
        GOON,1;
          ACT,,XX(26).EQ.1,WTTGT;                  STOP, TARGET
                                                   DETECTED
          ACT;
        ASSIGN,XX(15)=XX(16),
               XX(18)=XX(18)-1,    1;              CHANGE TGT LOCATION
                                                   TO NEW GRID
          ACT;
        EVENT,9,1;                                 PRINT MESSAGE ABOUT
                                                   TGT MOVE
          ACT;
        GOON,2;
          ACT,,,HFMVE;                             MOVE TARGET TO THE
                                                   CENTER
```

```
         ACT,STOPA(5);                          OF THE NEW GRID
       GOON,1;
         ACT,,XX(26).EQ.1,WTTGT;                STOP, TARGET
                                                DETECTED
         ACT;
       GOON,1;
         ACT,,XX(24).EQ.1,TOPRW;                STATUS=1, MOVE
                                                AGAIN BEFORE DWELL
         ACT,,,MOVE;                            STATUS=2, DWELL
                                                BEFORE MOVE AGAIN
;****  DELAY FOR DWELL TIME  ******************************
DLAGN GOON,1;
         ACT,XX(21);                            DELAY FOR DWELL
                                                TIME
       GOON,1;
         ACT,,XX(26).EQ.1,WTTGT;                STOP, TARGET
                                                DETECTED
         ACT;
       ASSIGN,STOPA=1,   1;                     RELEASE TGT ENTITY
         ACT;
       TERM;
;****  FUEL DECREASE  *************************************
FULDN GOON,1;
         ACT,XX(36);                            FLY ONE MORE
                                                MISSION SEGMENT
       ASSIGN,XX(6)=XX(6)-XX(37),    1;         DECREASE FUEL USED
                                                LAST SEGMENT
         ACT,,XX(26).EQ.1,WTTGT;                STOP, TARGET
                                                DETECTED
         ACT,,,FULDN;
;****  MOVE THE TARGET ONE HALF OF A GRID   ****************
HFMVE GOON,1;
         ACT,XX(20);                            DELAY FOR ONE HALF
                                                OF A MOVE
       GOON,1;
         ACT,,XX(26).EQ.1,WTTGT;                STOP, TARGET
                                                DETECTED
         ACT;
       ASSIGN,STOPA=5,   1;                     RELEASE TARGET
                                                ENTITY
         ACT;
       TERM;
;****  MISSION COMPLETION MESSAGE  *************************
E1MSG ASSIGN,XX(46)=1.,   1;
         ACT;
       EVENT,10,1;                              PRINT MESSAGE
                                                ABOUT NO SEARCH
;                                               TIME ALLOWED
         ACT,,,ENFLT;
E2MSG ASSIGN,XX(46)=2.,   1;
         ACT;
       EVENT,10,1;                              PRINT MESSAGE
                                                ABOUT ALL SEARCH
```

```
;                                               TIME USED
          ACT,,,ENFLT;
E3MSG ASSIGN,XX(46)=3.,   1;
          ACT;
        EVENT,10,1;                             PRINT MESSAGE
                                                ABOUT ACFT BELOW
;                                               MINIMUM FUEL
          ACT,,,ENFLT;
E4MSG ASSIGN,XX(46)=4.,   1;
          ACT;
        EVENT,10,1;                             PRINT MESSAGE
                                                ABOUT TGT DETECTED
          ACT,,,IDENT;
;****  END FLIGHT,NO DETECTION  ***************************
ENFLT ASSIGN,XX(11)=XX(11)+1,
               XX(12)=XX(12)+1,
               XX(26)=1,
               STOPA=1,
               STOPA=5,   1;                    COUNT AIRCRAFT
                                                MISSES AND
;                                               MARK TARGET FOR
                                                DESTRUCTION
          ACT;
        COLCT,XX(12),NUMBER MISSES;
          ACT,,,WTTGT;
;
;****  END FLIGHT, FOUND TARGET   **************************
;
IDENT ASSIGN,XX(11)=XX(11)+1,
               XX(28)=XX(28)+1,
               XX(26)=1,
               STOPA=1,
               STOPA=5,   1;                    COUNT AIRCRAFT
                                                HITS AND
;                                               MARK TARGET FOR
                                                DESTRUCTION
          ACT;
        COLCT,XX(28),NUMBER HITS;
          ACT,,,WTTGT;
;****  AIRCRAFT WAITS FOR ALL OTHER STRAY ENTITIES  ********
WTTGT ACCUM,4,4,,1;                             WAIT FOR ALL
                                                ENTITIES(AIRCRAFT,
;                                               TARGET,FUEL, AND
                                                DWELL/MOVE)
          ACT;
        ASSIGN,XX(29)=XX(28)/XX(11),   1;       COMPUTE FRACTION OF
                                                TGT'S FOUND
          ACT;
        EVENT,12,1;                             PRINT THE GRIDS THE
                                                AIRCRAFT SEARCHED
;                                               AND THE TIME THE
;                                               SEARCH BEGAN
          ACT;
```

```
        COLCT,XX(29),Pr DETECTION;
          ACT,,XX(11).EQ.XX(14),DONE;      RUN COMPLETE, FLEW
                                           MAX NUMBER
;                                          OF MISSIONS ALLOWED
          ACT,,,ACFT;                      FLY NEXT MISSION
;************************************************************
DONE    TERM,1;                            END RUN
        ENDNETWORK;
;************************************************************
INIT,0.,1000000.,NO/1;
SEEDS,0(1)/Y,0(2)/Y,0(3)/Y,0(4)/Y,0(5)/Y,0(6)/Y,0(7)/Y,
                                                0(8)/Y,0(9)/Y;
SIMULATE;
FIN;
```

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VITA

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Thesis Advisor: William F. Rowell, Major, USAF
Assistant Professor, Department of Operational Science

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This project simulates a bomber aircraft mission attacking a strategic relocatable target to develop the relationship between the timing of intelligence updates and the probability of detection. After one mission is simulated, the result is recorded as a hit or a miss. For one run using one update time, the percentage of hits from the total number simulated becomes the estimate for the probability of detection.

Target movement is modeled as Markov chain with aircraft missions simulated independently. The simulation is a combined network discrete-event orientation using SLAM and FORTRAN as the computer languages. Output routines track the target movement through a specified grid area as well as tracking the aircraft search patterns.

Results are displayed graphically by plotting the estimated detection probability against the corresponding update time used to arrive at the estimate. Procedures for developing confidence bands around the resulting plot are also discussed. More research is recommended in two areas: the search pattern used by the aircraft and procedures for estimating how long the aircraft has been in the observed position when an intelligence update is taken. The conclusion is that the time remaining before the aircraft arrives in the search area when the update is received should be less than half the total dwell time of the target in order to realize significant improvements in the detection probabilities.

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